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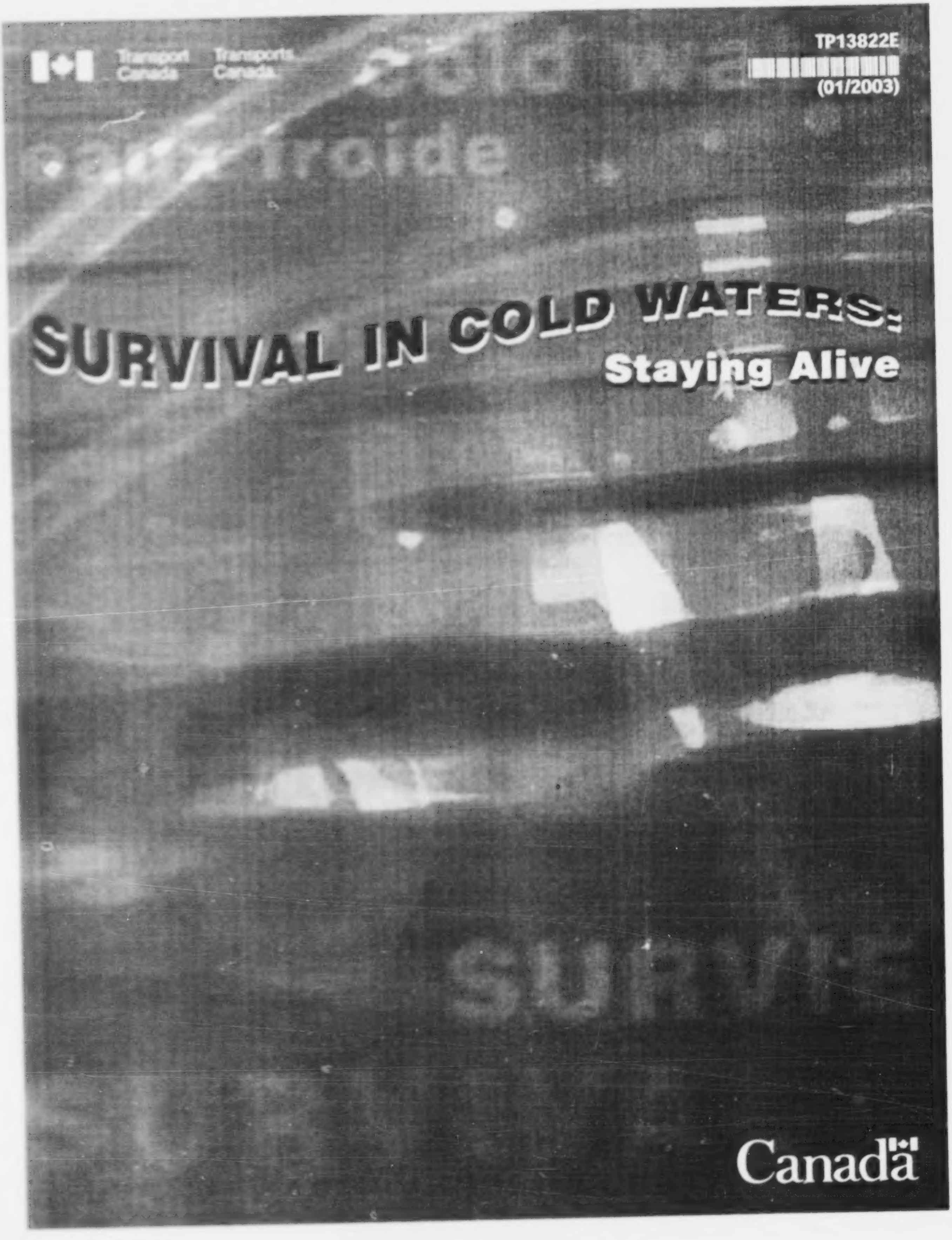

SURVIVAL IN COLD WATERS:
Staying Alive

Canada

Printed in Canada

Please direct your comments, orders and inquiries to:

Transport Canada
Marine (AMSRE)
Place de Ville
Tower C
330 Sparks Street
Ottawa, ON K1A 0N8

E-mail: marinesafety@tc.gc.ca

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TP13822E

ACKNOWLEDGEMENTS

As with the previous work that was conducted on behalf of Transport Canada on Survival in Cold Waters under PWGSC Contract No.T8275-010075/001/SS, I must give thanks to several people who aided in this report. First, it could not have been started without the help of Jim Brock and John Murray from the Marine Safety Directorate. They with Victor Santos-Pedro conceived the necessity of such a report.

It could not have been completed without the outstanding support of Professor Mike Tipton of the University of Portsmouth, UK and the Royal Navy Institute of Naval Medicine and his colleague Dr. Howard Oakley. Professor Frank Golden was invaluable in explaining the development of the 1983 IMO standard. They and Carole Tipton reviewed the initial draft and gave me very valuable advice on content and format. Dr. John Frim from DCIEM found me the table from Burton and Edholm's book. Bob Askew, Steve Portman, Rob Blair and Jim Hartt at Mustang gave me their valuable time to review the paper and advice on the technical way ahead in standards and design for the next generation of integrated survival suits. Professor John Kozey from Dalhousie University reviewed the final draft. Finally, Kimberley Howard must be thanked for all the long hours spent typing and formatting the report.

This has been a considerable undertaking to complete the literature survey, and it is hoped that it will improve the safety of all who work over or on the water. Marianne Harvey was of great assistance finding references from the IMO library in London U.K. The opinions expressed in this report are solely those of the author. He would be pleased to receive comments on them either electronically at chrisb@sstl.com, or by post at:

Dr C.J. Brooks
Survival Systems Limited
40 Mount Hope Avenue
Dartmouth, Nova Scotia
B2Y 4K9 Canada

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EXECUTIVE SUMMARY

1. It is quite astonishing that over the centuries, hundreds and thousands of humans have drowned in cold water, and it is only in the last 50 years that anyone has taken this death toll seriously. Death was attributed to drowning from an inability to stay afloat and vague terms, such as exposure. This is because death at sea was, and to some degree still is considered an occupational hazard. Fishermen for instance, who are most at risk, simply considered it as on occupational hazard and fate. Any attempt at protection was to float the person in rather than out of the water.

2. It took until the middle of the Second World War for the UK and Germany, and post-Korean war for the US to realize that there was a problem from sudden cold water immersion.

3. As a result, internationally over the last half of the 20th century, there has been considerable human experimentation in cold water physiology. The pioneering work was done in the mid-1940s and 1950s, but by the 1960s, it appears to have been forgotten and needed to be relearned. The advent of the offshore oil industry created a demand for more research to produce better immersion suits. This created a flurry of experimentation in the 1980s and 1990s. A number of these experiments have been cited to give the reader the wide scope of them.

4. Although the four stages in which death may occur in the cold water accident were known since the Second World War, stage one (cold shock) and stage two (swimming failure) were considered only of academic interest. As a result, regulators, teaching establishments and survival suit manufacturers all concentrated their efforts on protecting the human from hypothermia. In this regard they have done a very good job.

5. Even though there are well established teaching programs, good regulations and much improved life saving equipment, there are still in the order of 140 000 open water deaths each year. What has been overlooked is the significance of the first two stages - cold shock and swimming failure as a cause of death. The severity of the effects of cold shock is directly proportional to the water temperature peaking between 10-15°C.

6. The layperson and accident investigators are often surprised that some people do not survive a lengthy immersion. Theoretically they are within the "safe" boundaries of one or more of the survival curves that have been developed to predict death from hypothermia. These people do not die of hypothermia per se. They die from a variety of problems in which moderate hypothermia is enough for them to lose their physical ability and mental determination to keep their backs to the waves. They thus inhale the next wave and die from drowning in spite of wearing a life jacket.

7. In regard to immersion suits, Eskimos have used "spring pels" to protect themselves from sudden cold water immersion since they took to the water. Crude suits have been available to mariners since the mid 19th Century. A concentrated effort to produce a practical, commercially available suit did not occur until post 1945. Between the 1950s and the late 1970s, the suits were criticized due to poor design, poor fit, leakage and quality control in the manufacturing process. In the last 20 years, with the introduction of several standards, including the 1983 IMO SOLAS standard, improvement in fabrics, zips and better inspection procedures, the water tightness of the suits has improved, and acceptance has improved.

8. Fundamental principles of the immersion suit design and development are discussed, particularly the requirements for a dry suit, the necessity for it to be integrated with the lifejacket, the profound, negative effect of leakage on the immersed Clo insulation value, the difficulty of protecting the hands and the penalties for the use of poor materials and quality control in the manufacturing process.

9. Thermal manikin technology for evaluating the thermal protection of an immersion suit moved rapidly forward in the 1980s, but has stagnated

basically due to lack of funding. Although there are pros and cons for manikin use, the way ahead is to develop a simple manikin for suit thermal testing against a standard. Humans should only be used for new concepts and major modification to already approved suits. More research is needed to clarify the proportional contribution of torso, head and limbs to the heat equation in order to fine tune the next generation of manikins.

10. In regards to who should be protected and what regulations require modification or initiation, there are thirteen professional categories that require either a constant wear suit (Group I), a ship abandonment suit (Group II), or a passenger immersion suit system (Group III). Modifications are required to the standards related to the Group I and II suits, but most important, the Group III (passengers sailing in water below 15°C) are currently unprotected. In the next two years, Transport Canada should require the carriage of a Navy style quick don immersion suit, within the next five years, an integrated passenger immersion suit system must be developed.

11. In regards to the practical advice regarding the regulations requiring the carriage of liferafts and training of operators of passenger carrying vessels.

(a) Wherever possible, entry into water below 15°C should be avoided. Direct entry into a life raft should be the objective.

(b) Transport Canada should use this philosophy in the design, development and implementation of all new legislation in a step wise fashion. All vessels operating in Canadian lakes and rivers at 15°C or below should carry liferafts that can easily be launched and boarded by the entire crew and passengers.

(c) The only exception to this should be where it is physically or practically impossible to stow a liferaft. Under such conditions the passengers must wear inflatable lifejackets when on board.

(d) Operating a vessel close to the shore or in groups or the carriage of EPIRB are not reasons for waiving this requirement because death from cold shock will occur within 3-5 minutes, swimming failure in under 30 minutes, and darkness only hampers escape and rescue.

(e) The Marine Emergency Duties curriculum should be amended to include the two new Canadian videos on cold shock, swimming failure, hypothermia and post-rescue collapse.

12. A correctly designed and fitted lifejacket plays a vital role in the effort to protect the human from cold shock. Introduction of legislation and regulations since 1945 have had a dramatic effect on drowning statistics. These are at an all time low in Canada of 1.2 per 100,000 population.

13. This does not allow any complacency because work still needs to be done on the nomenclature of flotation devices (lifejacket v. PFDs), improvement in self righting tests, a review of self righting requirements, co-ordination of new standards with the IMO/ISO/CEN standards, and the question of legislation of the wearing of flotation devices on small passenger vessels. More attention should also be paid to how fashion positively or negatively affects the wearing of lifejackets and personal flotation devices.

14. If the decision is made to develop new standards for lifejackets (inshore and offshore) and PFDs (generally domestic and recreational) then because there is so much commonality between them, neither must be developed in isolation of each other. Furthermore, it is essential that preferably the committee chairman or senior representative for both standards should both attend each other's meetings and also international meetings with IMO/ISO/CEN. If this does not happen an incongruous situation may occur where common essential parameters may not be in agreement.

15. For those destined to develop the integrated immersion suit system, it must be remembered that:

(a) getting wet is potentially very dangerous

(b) a dry system must be provided to achieve protection from the four stages of immersion

(c) leakage of as little of 1/2 litre of water into the system will reduce insulation by 30%

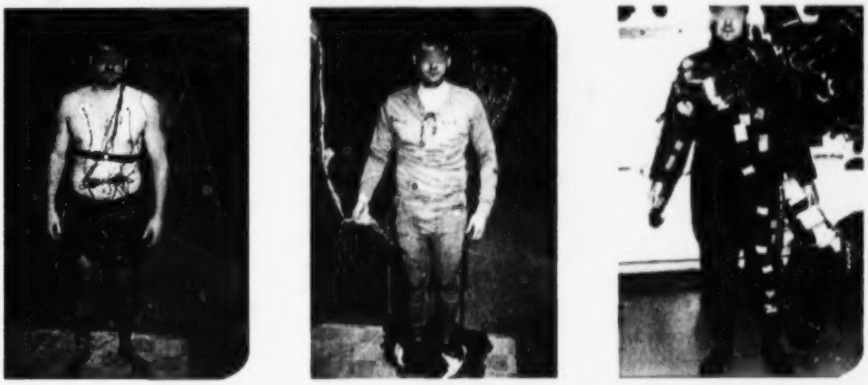
(d) the maximum insulation that can be added to a suit to prevent heat loss and still be wearable is 4.5 Clo in air

(e) protection of the hands in the longer term is problematic, but not essential to survival, providing function is maintained for critical tasks

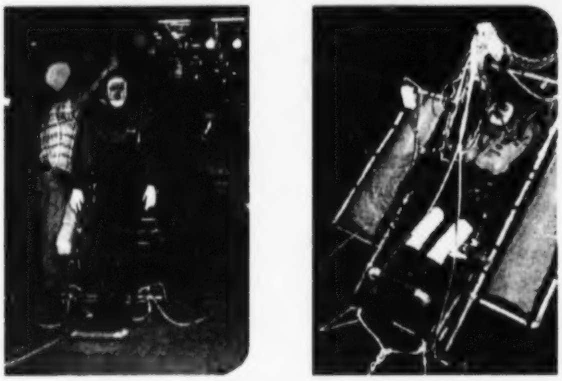
(f) testing should be as realistic as possible to avoid disappointment with the function of the final product in the survival situation

Frontispiece

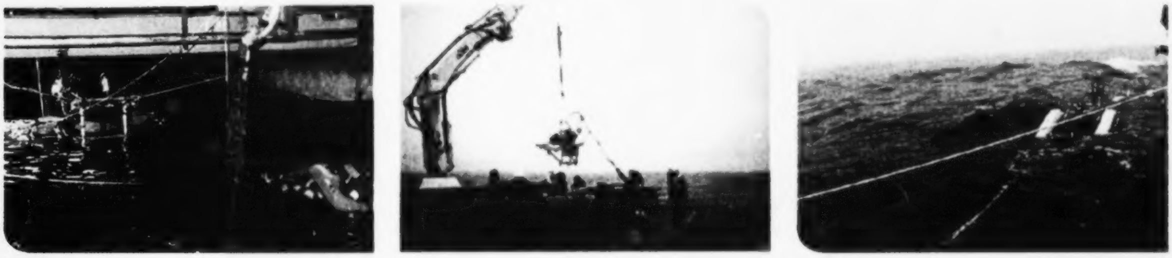
A Thermal Immersion Suit Experiment Using the Latest Technology with Humans and the Manikin in the Laboratory and at Sea.



Heat flow discs applied to skin of subject; inner liner donned and heat flow discs applied to this layer; outer shell immersion suit donned and heat flow discs applied to the external surface.



Thermal manikin prepared in exactly the same manner and ready to be loaded into cradle; manikin loaded in cradle and positioned at correct angle.



Manikin and human floating in the NRC Institute of Marine Dynamics wave tank; manikin loaded in cradle and ready to go to sea; manikin and human riding three metre waves in the Atlantic Ocean offshore in 2°C water, Halifax, Nova Scotia.

INTRODUCTION

This report was requested by the Marine Safety Directorate of Transport Canada to address the problem of survival in cold waters.

It is divided into six specific chapters: 1) a brief introduction to the problem; 2) the physiology of cold water immersion; 3) the research that has been conducted to protect the human from the dangers of sudden cold water immersion; 4) the design and development of current immersion suits; 5) the inter-relationship between the immersion suit and the lifejacket, and 6) a review of the different groups of people who fly over, work on or play on the water and what protection these groups need.

The report is designed to provide knowledge to a wide variety of people, for instance, on the one hand to pathologists and coroners conducting autopsies and investigations on drowned victims through to young physiologists starting their career in thermal physiology; from manufacturers of immersion suits to cruise ship operators required to provide protective clothing for their ship's company; and from naval medical officers and marine safety inspectors who need to understand the problems of the dangers of cold water to masters of fishing vessels who also need to know the problem and do not know where to get the answer. Therefore, each chapter has been written as a standalone chapter and can be read on its own. For those who wish to obtain only superficial knowledge and not delve into more detail, there is a summary of the contents at the end of each chapter, then the reader can skip to the next chapter of interest. It also incorporates the contents of the first edition of Transport Canada TP 13822E, published in August 2001, which specifically addressed the new knowledge gained on cold shock and swimming failure.

The Problem

Chapter 1

Currently within Canada, there are hundreds of thousands of persons being transported for business or pleasure over inland waterways, lakes and rivers. Moreover, there are thousands of Canadians who earn their living working on or flying over water. Depending on the local climate, transportation may occur throughout the year or be limited to when the passage is ice free. Irrespective, for a large portion of the year, particularly the winter, spring, and early summer, the water is cold.

Recently, (June 2000), there was an accident in Georgian Bay where two children drowned after the True North II sank within two minutes (Reference 162). The question has been asked as to what steps should be taken to prevent this from re-occurring. Carriage of lifejackets is already mandatory. Should there be any change in the regulations? Carriage of liferafts or immersion suits within Canada's internal waterways is not mandatory when operating close to shore. Should a change of policy be made on this requirement? If there are to be any changes in policy on the wearing of immersion suits, lifejackets or carriage of liferafts, should it be related to the physical water temperature at the time the vessel is operating? Finally, are Canadian national immersion suit standards adequate and how do they relate to the lifejacket standards and how do they interrelate to international standards? These questions will be addressed in the following chapters with conclusions and recommendations.

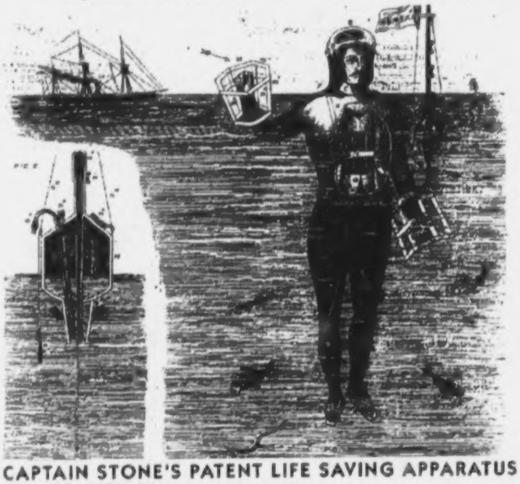
Drowning in Cold Water: How and Why Does it Happen?

Records of death from immersion in cold water date back to ancient times. Circa 450 BC, Herodotus (Reference 77) wrote of the sea borne expedition against Athens by the Persian general Mardonius. He clearly distinguished drowning from hypothermia, when he wrote, "Those who could not swim perished from that cause, others from cold" (Reference 56). In spite of hundreds of thousands of maritime disasters, the precise medical cause of death has been rarely noted. Death has commonly been ascribed to "drowning" or being "overcome by the sea". In the 18th and 19th century, James Lind (1762) mentioned the dangers of collapse after rescue (Reference 102), and James Currie (1797) observed deterioration of his subjects before improvement (Reference 41).

Loss of life at sea was accepted as an occupational hazard and fate. Wrecking was not made illegal until 1807 and the Royal Navy's use of impressment was not abandoned until 1815. Thus, such items as lifejackets, which could be used to aid escape were not encouraged. Shipwrecked sailors had to cling to wooden spars, and water and rum barrels (Reference 29). Since very early times, the Eskimos understood the dangers of sudden cold water immersion. They used suits called "spring-pels", these consisted of sealskin or seal gut stitched together to form a complete waterproof covering when sailing in their kayaks (Vanggaard, 1988) (Reference 168). A version of this suit is in the Danish National Museum (Willett, 1988), (Reference 172) (Bricket-Smith, 1924), (Reference 26). However, this concept was not adopted by professional mariners and fishermen.

Little specific design of immersion suits was conducted until the middle of the 19th Century. The only work on survival equipment had been the pioneering work of Captain John Ross Ward in the development of a life jacket in 1851 for the National Lifeboat Institution (Reference 99). In 1869, Captain Stoner invented a patent life saving apparatus, which was revolutionary for the time and addressed all the fundamental modern day requirements of a survival suit. It included a waterproof suit, a lifejacket, head protection, a signalling device and paddles for aiding passage through the water (Figure 1) (Reference 44).

Figure 1: **Captain Stoner's Patent Life Saving Apparatus**



CAPTAIN STONE'S PATENT LIFE SAVING APPARATUS
NO. 20, VOL IX

Lee (1960) reported that: "An exposure suit was brought from America by Merriman in about 1870. It consisted of a complete waterproof dress with the upper part inflated with air, and it protected the body from loss of heat; the face was the only part of the body exposed. When inflated it had a buoyancy of 30 lbs[1]. The Board of Trade bought a number of them in 1872 and supplied one to each of their Lifeboat Stations." (Reference 96). With the advent of iron ships around 1850, not only did the ships sink faster, but also there was less flotsam for flotation. Consequently, there was an increase in the loss of life at sea. In 1871, it was reported that 2740 British seamen lost their lives through drowning (Reference 29).

Aury (1955) reported that: "In 1875, Captain Boyton, wearing an inflatable swimsuit, attempted to cross the English Channel, propelling himself by paddles and a small sail. He had to give up after sixteen hours in the water. In a second attempt two months later, he carried provisions, rockets and a trumpet and successfully crossed from Cape Gris Nez to Dover in 24 hours" (Reference 12).

No one paid attention to the observations by Lawrence Beesley (1912) (Reference 20). He was a survivor from the Titanic who noted that the victims wearing lifebelts and in cold, but calm water had died of cold. The official cause of death was given as drowning. Although the International Safety of Life at Sea (SOLAS) Committee was formed directly as a result of this accident, no thought was given to personal protection. Everyone was obsessed with floating in and not on the water. In 1912, Mr Boddy demonstrated his "Boddy" Life Saving jacket in the English Channel off Cowes, but his efforts came to nought even though it was approved by the Board of Trade for aviation (Reference 1).

Following the Empress of Ireland accident in 1914, a Mr Macdonald of Portland, Oregon demonstrated his waterproof rubber survival suit and lifejacket in the harbour in Montreal, but no one paid much attention to it (Reference 29). 12,000 British merchant seamen and 5354 German naval officers and men drowned during World War I, yet again, no one asked why (Gilbert, 1994) (Reference 50). Toward the end of that war, Walter Fry developed a lifesaving suit, which was tested by the US Navy in January 1918 at the Brooklyn Navy Yard, but nothing seems to have come out of that either (Hiscock, 1980) (Reference 79). Ultimately, the US Navy and Coastguard developed a combination flotation and exposure garment for aviators. The "Dreadnaught Safety Suit" made of rubberized material and padded with kapok was reported to be in use at the Naval Air Station Pensacola in the winter of 1918 – 1919 (Reference 29).

After World War I, the British Merchant Advisory Committee met in 1922 to review lifesaving appliances (Reference 112). Their review of passenger ships lost between 1914 and 1922 revealed that, 10,024 (21%) of crew and passengers had lost their lives. The whole report concentrated on the multiple failures that occurred in the mechanics of launching lifeboats into the water. One very small section was devoted to a simple applied cold water physiology experiment conducted by Hill on the effect of clothing on the laboratory assistant Mr. Pergarde, protected by a Macintosh coat or sack, and oil skin coat and waders. He was exposed to water temperatures down to 16°C. The significant conclusion was:

> "that the coverings wet or dry, protect a body from cooling down, and also that a rubber skin outside such coverings is a further great protection against such cooling down".

Yet, no one acted on this profound and correct statement, nor did any recommendations pertaining to this discovery appear in the extensive report; it was hidden away in one of the Annexes!

In 1928, the Vestris foundered off Chesapeake Bay and 112 passengers and crew perished. The SOLAS committee was recalled, but no advice was given to do research on personal protection. The only positive step taken in 1928 was the use of a tailor's dummy or manikin to investigate the performance of the lifejacket and protective oilskins in turbulent seas. This had been precipitated by the loss of all

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[1] Throughout the report, buoyancy will be reported in imperial pounds, kilograms or Newtons depending on the year of the test and the current nomenclature. (1 kg = 2.2 lbs = 9.8 Newtons)

17 crew of the Rye Harbour lifeboat in the English Channel (Reference 100). The policy, right up the Second World War and the following ten years was still to rely on flotation in rather than on the water using lifeboats, Carley floats and a series of Balsa, Spanner or Denton rafts.

It was the inadequacies of life saving equipment during the Battle of the Atlantic in the Second World War that was the catalyst for scientific examination of the problem. The progress of the design and development of immersion suits will be discussed in Chapter 2.

As Golden (1996) (Reference 57) clearly pointed out, official inquiries in an endeavour to prevent a recurrence, have been more interested in the cause of disaster than the cause of death of the crew and passengers. This is still the case as we enter into the 21st century. The recent issue of the Marine Investigation Report by the Transportation Safety Board of Canada on the sinking of the "True North II" in Georgian Bay June 2000 extends to 63 pages (Reference 162). There are only five sentences assigned to the fact that two grade seven students died. One of the sentences curtly states: "The bodies were subsequently examined by the coroner who determined that the cause of death was drowning." There has been no thought put into why they drowned or even if they could swim in the first place. Thus, both funding and direction for physiology and human factors research has sadly lagged behind the technological advances in ship design.

The Knowledge: Physiology of the Immersion Incident to 1995

The Medical Research Committee (Reference 110) published a pamphlet in 1943 on "The Guide to the Preservation of Life at Sea After Shipwreck". This was based on the observations of naval medical officers who had treated survivors, and on 279 survivor interviews. This was the basis from which all the modern physiological research has been conducted.Two other reports were to follow after the War that revealed the shocking loss of life at sea which could have been prevented. The first was the Talbot Report (Reference 147) published in 1946.This showed the inadequacy of the RN lifebelt and the Carley type floats. Over 30,000 men died after escaping from their ships, in other words, during the survival phase. The second was the Medical Research Committee report by McCance et al (1956) which investigated "The Hazards to Men in Ships Lost at Sea 1940 – 1944" and examined the cause of death at sea in greater detail (Reference 108).

The pioneering work post-war was conducted under the auspices of the Royal Navy Personnel Research Committee and subsequently the Royal Navy Institute of Naval Medicine. This was basically summarized in Professor Keatinge's monograph (1969) (Reference 92). As a result of all the aforementioned information, it had become clear that the human body cannot maintain its internal temperature when immersed in water below 25°C when conscious and shivering. The body temperature must progressively fall until death occurs. However, there was much more to the problem than this.

Golden and Hervey (1981) (Reference 56) identified four distinct stages in which a human immersed in cold water may become incapacitated and die. However, what is most important to note is that stages 1, 2 and 4 were largely regarded as of academic interest only; so they did not have a large effect on survival policy, international regulations and survival equipment. All of the effort was concentrated on stage three, that of hypothermia, on predicting the onset and prevention of hypothermia. Thus, there is still no consideration given to the physiological impact resulting from the first two stages of immersion in the design of emergency equipment. For instance, flares are still vacuum packed in polythene bags and as in the Estonia accident were not usable simply because no one had the grip strength or the tactility to open the bags. The bailer in the Estonia liferaft was wrapped in polythene and after attempting to open it with his teeth, one survivor finally gave up after he had lost several teeth!! (Reference 43) Anyone who works, flies or plays over cold water, those who design equipment for emergency use, and coroners and pathologists who investigate deaths in marine accidents must know about these four stages.

Stage 1. Initial immersion responses or cold shock

On initial immersion, there is a large inspiratory gasp followed by a four-fold increase in pulmonary ventilation, i.e. severe hyperventilation. This on its own can cause small muscle spasms and drowning. Along with this, there is a massive increase in heart rate and blood pressure. These latter cardiac responses may cause death, particularly in older, less healthy people. These effects last for the first two to three minutes, just at the critical stage of ship abandonment (Tipton, 1989) (Reference 153), (Tipton et al., 1994) (Reference 157).

Death from cold shock is not uncommon. These are typical examples that continue to be regularly reported in the Canadian press each year and demonstrate the practical evidence that cold shock kills.

Teen drowns after lunch-hour plunge (Globe & Mail, April 16, 1998)

Toronto – A 14-year-old high-school student drowned yesterday after jumping into the frigid water of Lake Ontario. Hours after the incident, police still did not know why Peter Arthur went into the water, which was only about 4 degrees. There were two other teenagers with him at the time. When Peter failed to surface, his friends sought help from nearby construction workers, who called the police. When they arrived they jumped into the lake, which is about $3^1/2$ metres deep at that location, and searched for the missing teen for 10 minutes, until the icy water forced them to shore Sgt. McCann said. As the two officers sat on nearby rocks, huddled in blankets, members of the Toronto police marine unit arrived and took over the search. Dragging the area with a net, they located the teen, who by that time had been in the water for about 30 minutes. Firefighters performed cardiopulmonary resuscitation until paramedics arrived to continue treatment. But Peter was pronounced dead at Toronto East General Hospital at 12:55 p.m.

Reveller drowns after attempting polar bear swim (Globe & Mail, January 3, 2000)

A man celebrating the New Year at a party on a frozen lake drowned when he jumped into a hole cut in the ice. Adrian Weber, 38, was playing hockey with 25 friends on New Year's Eve on Kingsmere Lake when he attempted a polar bear swim between two holes cut two metres apart in the ice. Mr. Weber dived in at 1:30a.m. When he failed to resurface, friends jumped in but were unable to find him. His body was recovered Saturday by firefighters, close to the spot where he had jumped in. "The water was only about waist deep and he tried to swim between the two holes," his 44-year-old brother Christoph Weber said. "He must have got disoriented." "His friends dove in right away with a rope and tried to find him. They drove a car onto the ice and pointed the headlights of the car toward the hole to get some kind of light onto the lake. It was dark and hard to see anything." Mr. Weber said his brother was healthy and a good swimmer.

Hope fades in Newfoundland for teens swept into ocean in Pouch Cove (Mail Star Chronicle Herald, March 9, 2001)

Hundreds of people lined the shore of this tiny coastal community Thursday night as hope faded for three teens who were swept into the ocean while playing on ice floes. Police said four males between the ages of 16 and 18 were jumping from ice cake to ice cake about 50 metres from shore when one of them fell into the frigid water and slipped under the ice. The others tried to rescue him, but two were knocked into the ocean by a wave. The fourth teen made it back to shore. A woman who didn't want to be identified said people on shore tried to rescue the teens with a rope. She said one of them tried to grab the rope, but was too weak and couldn't hold on.

Stage 2. Short-term immersion or swimming failure

Death at this stage, between three and thirty minutes after immersion, appears to affect those who try to swim. It has now become apparent that much more emphasis must be put on swimming failure as a cause of death. It must also be understood that ability to swim in warm water is no indication of how well a human can swim in cold water. The classic testimony heard in the coroner's court is: "We saw him go over the side, he started to swim and by the time we had the boat turned around and tried to identify where he was lost, he had disappeared. How could that be? He was an excellent swimmer."

The cause was thought to be due to the respiratory and cardiovascular responses already started in the initial immersion. An alternative theory was that the cold water contact with the nose and mouth induced the "diving response". This causes breathing to stop (apnea), a slowing of the heart rate (bradycardia) and even cardiac arrest (asystole).

These are not rare events either and are commonly reported in the newspaper.

A sad start – two accidents in one weekend (Halifax Herald, June 18, 1996)

In Chester Basin, a 37-year-old woman drowned while attempting to swim across Gold River to the Goldwater Marina. About forty people including RCMP, firefighters and Coast Guard personnel undertook a search. Her body was found an hour later.

Michelle Yetman was suntanning with a friend shortly after 5 p.m. when she heard cries for help coming from the water. At first she thought it was just children playing around, she said. But then she realized it was for real. " I guess he lost his breath…so I ran in the water and swam as fast as I could to get out there," said Michelle, who happens to be a junior lifeguard. "It was so cold, I felt like I was hitting ice." When she reached the man, she helped the woman he had been swimming with – who had called for help – keep him above water until another rescuer arrived in a canoe. Then she helped load the man into the canoe, which took him to shore.

Son helpless as mom died (Daily News, June 5, 2002)

A Chester man who can't swim watched Tuesday as his mother was overcome by frigid, choppy water off Quaker Island, Lunenburg Co. Kathleen Haase, 44, and her son Michael, 25, were spending the day exploring the small grassy island about two kilometers south of Chester. When their small speedboat started to drift away from the island as the tide rose, Kathleen Haase tried swimming after it. She could swim, but the water Tuesday was only about 10°C. Wayne and Geraldine Truck were going past the island in their 11-metre sailboat when they heard the son's distant screams for help. "We didn't see anyone splashing in the water," Wayne Truck said. "She undoubtedly had succumbed." They caught the drifting speedboat and were bringing it back to the island when they discovered Kathleen Haase floating face down in the "bitterly cold" water, about 50 metres from the shore. Rescue crews worked to revive her on the boat ride and in the ambulance to South Shore Regional Hospital in Bridgewater. But she never recovered and was pronounced dead in hospital.

There are several common threads in these types of accidents:

- the victims were good swimmers
- the water was cold
- death occurred within a matter of only minutes - much too early for hypothermia to set in
- they were all healthy people
- they were often in shallow water
- the accidents occurred within feet of the shore.

Most important, there was potential help at the scene of the accident, but no one recognized the danger of sudden death from cold shock in an otherwise healthy person. This is the precise reason why standards for wearing lifejackets and/or carriage of liferafts must not be relaxed when operating in cold water. Carriage of EPIRBs (with their 90 minute to 2 hour response time), and the fact that the vessel may be operating in a group or close to shore are not reasons for a waiver.

The clear message is that sudden entry unprotected in cold water is very dangerous and should be avoided wherever possible. This applies to everyone whether commercial operators or recreational boaters.

Stage 3.Long-term immersion or hypothermia

Heat Balance: The Basic Physics

In order to understand the cause of hypothermia, it is important to understand the basic physics of how a human maintains heat balance.

Heat flows down a thermal gradient from high to low temperatures. Thus, in the cold, a thermal gradient is established, down which heat "flows" from the warmer deeper tissues to the cooler tissues near the surface of the body. Heat then escapes from the body to the environment. In normal circumstances in air, the body can exchange heat with the environment via four physical processes: radiation (R), convection (C), conduction (K), and evaporation (E).

R (Radiation). All objects possessing heat, including the body, emit thermal radiation from their surfaces.

C (Convection). This is the process by which heat is exchanged with the environment by the movement of air or water molecules adjacent to the skin, as they move away they are replaced by colder molecules.

K (Conduction). This term is used to describe heat exchange between the skin and surrounding surfaces with which it is in direct contact.

E (Evaporation). Evaporation is the process by which energy transforms liquid to a gas. The heat required to drive this process is removed from the surface of the object on which evaporation is occurring, and it cools.

For body temperature to remain stable in a cool environment, the heat produced by the body at rest or through exercise or shivering (M), must match that lost by R, C, K and E, or combined, R+C+K+E=M.

Several factors influence the amount of heat exchanged by R,C,K, and E. The most common are: the surface area involved in heat exchange; the temperature gradient between the body and the environment; and the relative movement of the fluid (air or water) in which the body is placed. This explains why someone will cool faster if: they are in colder water (gradient); they are partially immersed compared to completely immersed (surface area); they are in fast flowing as opposed to still water (movement of the fluid); they move about compared to staying still (relative movement of the fluid).

In water, heat is conducted to the molecules of water in contact with the skin ("boundary layer"), these molecules are warmed and rise (Convection), and are replaced by cooler ones. Thus, in water only two of the four primary pathways for heat exchange are available, and heat loss is principally by convective and conductive heat exchange. Despite this, a naked individual in cold water will cool approximately four times faster than in air at the same temperature. This is because thermal conductivity of water is 25 times that of air, and its volume-specific heat capacity is approximately 3500 times that of air. Therefore, water has a much greater capacity to extract heat. (The volume-specific heat capacity is obtained by multiplying the specific heat of a substance by its density. It represents the amount of heat required to raise the temperature of a given volume of water by 1°K. At 37°C the volume-specific heat capacity of water is 3431 times that of air.) Furthermore, when in water, unlike air, the surface area available for heat exchange with the environment comes close to 100%. This is the reason why cold water is so dangerous. The corollary to this is that hot water is a very good medium to re-warm hypothermic victims.

After thirty minutes or more of immersion, death may occur from hypothermia. The reason for this is that water has a specific heat 1000 times that of air and a thermal conductivity of about 25 times that of air. Thus, when a body is immersed in water below body temperature (37°C), it will inevitably cool to hypothermic levels at a rate dependent on:

- Temperature differential
- Clothing insulation
- Rate of agitation of the water
- Body heat production produced by shivering and exercise
- Ratio of body mass to surface area
- Subcutaneous fat thickness
- State of physical fitness
- Diet prior to immersion
- Physical behaviour and body posture in the water

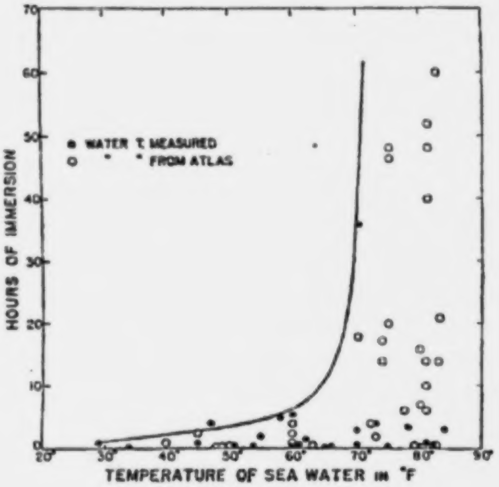
As the deep body temperature falls, humans lapse into unconsciousness. Death may occur in two ways – drowning through incapacitation, and cardiac arrest. Death from drowning will occur in a lightly dressed individual even wearing a lifejacket, approximately one hour after immersion in water at 5°C, or two hours in water at 10°C, or in six hours or less at 15°C (Reference 57).

If the deep body temperature continues to fall, death occurs on average from cardiac arrest somewhere below a body core temperature of 24°C. The lowest recorded survival temperature in an accidental victim is 13.7°C (Reference 51). However, after surgical induction of hypothermia, there has been one reported incident of resuscitation from a body core temperature of 9°C (Reference 122).

Survival predictions were made from experimental data and case histories from shipwrecks. The first classic survival curve was published by Molnar in 1946 (Figure 2) (Reference 115). Included in here was the data from the Dachau prisoners (Reference 4). Survival predictions were later produced by Hall (1972) (Reference 65), and by the Canadian Red Cross from work conducted by Professor Hayward (1975, 1977, 1984) at the University of Victoria (Figure 3) (References 69, 70, 71 and 73).

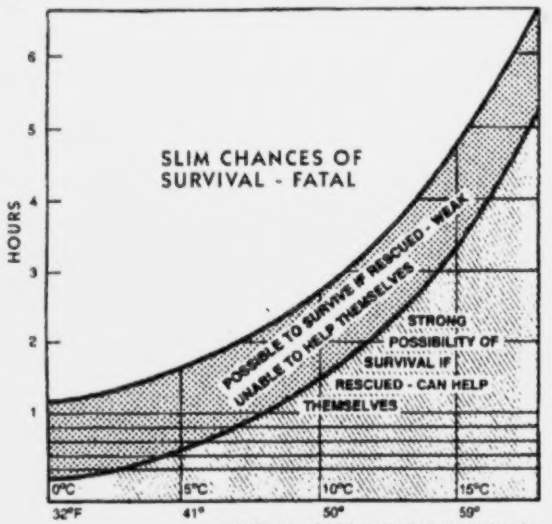
A later predicted survival curve was published by Hayes et al (1987) derived from Professor Eugene Wissler's Cold Water Survival Model (Figure 4) (Reference 67). From this and the combination of previous work, Tikuisis (1995, 1997) has published the latest prediction of survival time at sea level based on observed body cooling rates (References 149 and 150).

Figure 2 (After Molnar 1946) – Duration of immersion of shipwreck survivors in ocean waters of diverse temperatures.



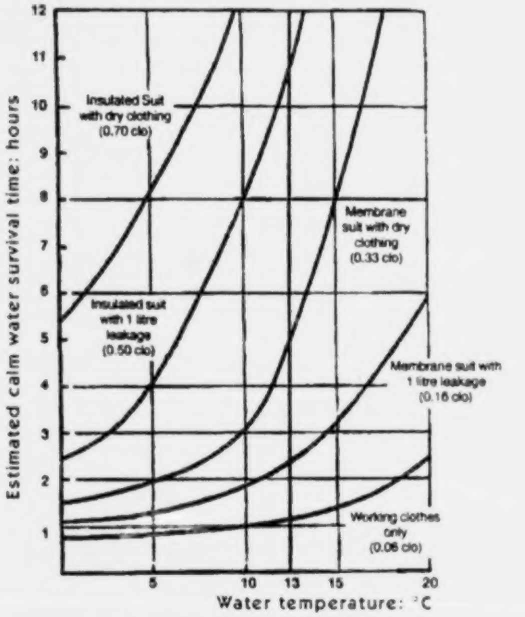
(The data are from the files of the Bureau of Medicine and Surgery, US Navy. Open circles, sea-water temperature was measured at time of rescue. Black dots, sea water temperature was obtained from the World Atlas of Sea Surface Temperatures on the basis of date and location of shipwreck or rescue. Each point represents the survival of at least one person.)

Figure 3 – **Cold Water Survival (Canadian Red Cross)**



SOURCE: :"COLD WATER SURVIVAL"
CANADIAN RED CROSS

Figure 4: **Predicted survival time against sea temperature for different levels of immersed clothing insulation (as derived from Wissler Model, Modified by Hayes, 1987).**



A summary of current predictive curves is given in Oakley and Pethybridge (1997) (Figure 5) (Reference 126). From this work, it became possible to give advice that survival times could be extended if the survivors stayed still in the water and did not attempt to swim to keep warm. Furthermore, adopting a fetal position with legs together and arms to the side, or folded across the chest prolonged survival time (References 5, 53, 71, 89 and 125). All of these predictive curves are premised on the fact that the person using the curves is prepared to accept the assumption that death is due to hypothermia. **They are all based on time to incapacitation.**

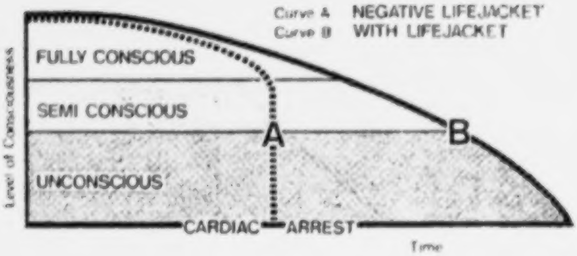
Figure 5: **Predicted periods (in hours) of immersion at different temperatures which are expected to result in "likely death". (After Oakley and Pethybridge (1997)**

Water Temperature	*Molnar, 1946 (Reference 115)*	*Keatinge, 1969 (Reference 92)*	*Nunnely & Wissler, 1980 (Reference 115)*	*Allan, 1983 (Reference 5)*	*Lee & Lee, 1989 (Reference 98)*
5°C	2.3	0.9	1.1	1.5	1
10°C	4	N/A	2.6	2.5	3
15°C	N/A	4.5	3	9	7

If the immersed person has survived the initial two stages of immersion, i.e. cold shock and swimming failure, then the next hurdle to face is hypothermia. It is now known that this per se may not be the cause of death. These curves must be used with caution. As Golden pointed out in 1996 (Reference 57), the predicted 50% survival times for fully clothed men in water wearing lifejackets are 1 hour at 5°C, 2 hours at 10°C, and 6 hours at 15°C. Yet these figures are difficult to validate in the laboratory where the body temperature only falls about two or three degrees in the equivalent time. There must be another cause of death. Golden explained that a conscious survivor in a seaway will make the physical effort to keep his/her back against the waves, but when physically impaired through muscle cooling, semi-conscious and with a loss of determined will to survive, both of which occur after a body core temperature drop between 2-3°C, then the survivor turns into the waves and drowns. He also emphasized the point that death will occur much

quicker from drowning if a lifejacket is not worn (Figure 6) (Reference 54).

Figure 6: **Empirical curve correlating deterioration in consciousness to time, in an immersed body with (B) and without (A) a lifejacket. Courtesy of Prof. Frank Golden.**



Markle (1991) provides several classic examples of death from hypothermia in water below 15°C in his US Coast Guard Report on lifesaving systems for small passenger vessels (Reference 106).

COMET, May 1973

The COMET had 27 persons on board and sank in Block Island Sound, Rhode Island, about seven miles offshore, in 48°F [9°C] water. The COMET had no EPIRB and the only lifesaving apparatus was a 20-person buoyant apparatus. About 15 of the survivors held onto the buoyant apparatus at some point, including two of three who set out in a swamped dinghy to get to the buoyant apparatus. Six others were able to use an 8' X 10' piece of flotsam for partial support. Almost everyone on board had a lifejacket on when they abandoned ship. The two or three people who were not able to get a lifejacket were able to use either the buoyant apparatus or the flotsam. The first death occurred in the dinghy about 1/2 hour after the sinking. Deaths continued until rescuers happened on the scene 4 hours later. A total of 16 persons died in this time.

JOAN LA RIE III October, 1982

The JOAN LA RIE III had 22 persons on board and sank about 8 miles off of the New Jersey coast in 53°F [11.6°C] water. Life saving apparatus consisted of a 7-person buoyant apparatus and a 15-person life float. Most of the passengers were resting in the deckhouse when the vessel was hit by a rogue wave, heeled over, and began to flood. Two persons are missing as a result of this casualty. They may have drowned in the deckhouse. The remaining 20 persons were able to escape into the water, but none was able to put on a life jacket. Apparently all but two persons made it to the life float and buoyant apparatus, which were secured together. Those two died. Of the remaining 18 gathered at the life float and the buoyant apparatus, 14 survived and 4 died in the 90 minutes it took for the rescue to arrive.

The argument that liferafts are not necessary because vessels operating near shore in day time can expect other vessels to come to the rescue quickly is not supported, nor is the addition of an EPIRB going to speed up rescue to this type of response time. As already stated, death will occur within 3-5 minutes for those who have not donned a life jacket, or from swimming failure within 30 minutes if not clothed properly and supported by a lifejacket. Markle (1991) came to precisely the same conclusion.

Stage 4 - Post-rescue collapse

Up to twenty percent of immersion deaths occur during extraction from the water, or within hours after rescue (Reference 57). This was first noticed in 1875, by Reinke, a police surgeon in Hamburg. He recorded cases of sailors who had fallen into the canals and harbour and died within 24 hours of being rescued (Reference 55). During the Second World War, the Germans and Allies noted that some of those who were rescued alive, died shortly afterwards. Matthes (Reference 109) noted how ditched German aircrew who had been conscious in the water and aided in their own rescue, became

unconscious and died shortly afterwards. McCance et al, (1956) (Reference 108) found that seventeen percent of those shipwrecked survivors rescued from the water at 10°C or less died within 24 hours of rescue. None of the people rescued from water above 20°C died.

When the Wahine Ferry sank in 1969 in Wellington Harbour, Mercer (Reference 113) reported that, of the 51 lives lost, twelve were alive on rescue, but died shortly afterward. In the 1994 Estonia accident, at least one person who was noticed to be alive in the water, lost consciousness when in a helicopter hoist, fell back into the sea and died. An extensive list of post rescue collapse incidents is reported in Golden's articles on shipwreck and survival (Reference 55) and Golden and Hervey's article on the after-drop and death after rescue from immersion in cold water (Reference 53).

The Initial Responses to Immersion (Stage 1 and Stage 2) – New Scientific Information Since 1975

It has now become clear that over half of the immersion-related deaths occur during the first two stages of immersion, i.e. cold shock and swimming failure. However, as stated previously, investigators still concentrate on the cause of the marine accident and not the precise cause of an individual's death. It is still hard to accurately document at what stage of the immersion death occurred. This is because little history has been gathered from survivors or by investigators. It is only possible, to a limited degree, to estimate the cause of death from a newspaper report or the scant information in the accident investigation. The problem is further compounded by the fact that such a good job has been done educating people on the dangers of cold water, immersion and hypothermia, that even the pathologists now list the cause of death as hypothermia, even though the cold, wet body on their autopsy table actually died from cold shock or swimming failure and drowning.

Although cold shock or an increased respiratory response to cold water has been known for many years (Falk, 1884) (Reference 45), the practical significance of this response has only really been evaluated in terms of its practical importance in the last 20 years. When considering at what water temperature protection should be provided against the initial responses to cold water immersion, it is now known that the cold shock response begins at water temperatures below 25°C (Reference 90) and peak at a temperature between 10-15°C (References 154 and 155). This is in part, the explanation for deaths that occur in water as high as 15°C long before standard survival curves would predict. It is now thought by many that the pressing threat to otherwise healthy individuals is the respiratory distress evoked by immersion and the consequent inability to control breathing and breath hold.

Swimming has a massive impact on the rate of body cooling and can increase the rate between 30-40% (Reference 92). Tipton et al (1999) (Reference 160) studied the deterioration of swimming performance after the subjects had adapted to the stage 1 cold shock respiratory responses. All ten competent swimmers completed a 90-minute swim in 25°C water; eight completed the swim in 18°C water. In 10°C water, five swimmers completed 90 minute swims, four were withdrawn between 22 and 50 minutes close to swim failure and one was withdrawn at 61 minutes close to swim failure. Stroke rate and length were similar in 25°C and 18°C water throughout the swims, but in 10°C water the stroke rate was increased and the stroke length decreased. These changes were most pronounced in those close to swim fatigue. Stroke length decreased by 50% during the last 30 minutes for the swimmer who reached swim failure in 61 minutes.

Coincident to this, the average swimming angle increased from an average of 18° at the start of the swim to 24° at the end of the swim. The swimmer who reached swim failure finished with a swim angle of 35°. After 15-30 minutes in 10°C water, swimmers' fingers were splayed and started to flex. At the end of the swims, swimmers reported that it became increasingly difficult to straighten their limbs and coordinate swimming movements. Grip strength was not altered by swimming in water at 25°C, but in water at 18°C and 10°C, it was significantly decreased by 11% and 26% respectively.

Wallingford et al (2000) (Reference 170) investigated the factors which limit cold water swimming distance while wearing a personal flotation device. Five female and twelve male subjects took part in a swim in 14°C water. The subjects swam an average of 889 metres before swim failure. There was no correlation between distance swum and percentage body fat, aerobic fitness and abdominal skinfold thickness. However, those who swum the greatest distance had a significantly larger tricep skinfold thickness.

Wallingford et al. agreed with the conclusion made by Giesbreicht (1995) (Reference 49) that the majority of the decrement in arm performance is due to the local cooling of arm tissue and not due to hypothermia. Wallingford's study did not support the assumption made by Hayward et al (1975) (Reference 70) that hypothermia could be responsible for the inability to swim in cold water while wearing a personal flotation device. If Hayward's prediction was correct, the swimmers would have covered a distance of 2058 metres before incapacitation. This was more than double the distance of 889 metres covered by the subjects long before incapacitation from hypothermia (end average core temperature of 35.8°C).

Markle (1991) (Reference 106) correctly noted that persons in the water with and without lifesaving equipment died at a much higher rate than predicted by the estimated survival graph. This supports Golden's theory that many victims drown during the cold shock and swimming failure stage of immersion, not from hypothermia per se. Even if they survive long enough to cool, cold-induced muscle incapacitation can prevent their keeping their backs to the waves, and thus their oro-nasal cavities clear of water, sometime after their body core temperature is reduced 2-3°C. This is why it is essential to wear a lifejacket with good sea keeping properties, i.e. self-righting, good freeboard and a face shield to protect from hypothermia.

Markle further concluded that "The present requirements for lifejackets, life floats and buoyant apparatus have proven adequate in all studied casualties where water temperature was 15°C or less". This might have been the case in this study, but it is still possible to die from hypothermia and post rescue collapse as in the case of the Lakonia in 1965 that sank in 17.9°C water off Madeira (Reference 91).

The provision of a buoyant apparatus in which the survivor is basically floating with head only out of the water clinging to a becketed line in water below 15°C is only a last ditch measure if everything else has failed. Drowning is very likely from cold shock and swimming failure, in the short term, and hypothermia and post rescue collapse in the long term. The colder the water, the greater the chance of death. Again, as Markle clearly pointed out, in the case of the Cougar accident, the two people who managed to get themselves on top of a buoyant apparatus were the two not to be hospitalized. The remainder had to remain clinging to it in water at 13°C, three died. Similarly, in another case referred to by Markle (Zephyr II accident), if the device had been a liferaft instead of a buoyant apparatus, the person without the lifejacket would have been able to board it and would have survived the few minutes in the water. In this accident, eight of the survivors got separated from the boat. They decided to swim to an island, only one was alive six hours later when he called for help when almost ashore.

A Typical Case Where Death was Incorrectly Attributed to Hypothermia

Paradoxically, as previously stated, we have done a very good job of educating the public about hypothermia. As a result, local rescuers, police, the Red Cross, coroners and pathologists always assume that someone who has been pulled out of cold water drowned form hypothermia, yet this often is not the case. Because this assumption has been made, little further questioning has been conducted to find out precisely how, when and where the victim met his/her demise. The Ocean Ranger sank in near freezing water on the Grand Banks off Newfoundland in February 1982 with the loss of all 84 men. No one was outfitted with a survival suit, although some wore lifejackets. The cause of death was attributed to drowning from hypothermia, yet from the testimony available, many died after only a matter of a few minutes in the water.

Below is the testimony from the Master of the Seaforth Highlander (Reference 118).

It was at that time that the lifeboat began to capsize to port in a very slow manner, like watching a slow motion picture. The men standing on top of the boat were thrown into the sea. The boat remained capsized. I believed during the capsize of the lifeboat the line we had made fast to it parted. After it had capsized it was approximately 12 feet maybe off the Seaforth Highlander, and I could see what I estimate to be eight or nine men clinging to the boat in the water. I could see all these men. They had lifejackets on, and there was a light on each lifejacket....We were still along the lifeboat, and after maybe a minute and a half or two minutes – it is very difficult to estimate – the men clinging to the boat began to let go, and they drifted down my port side. At that point I shouted down to the mate on the deck via the loud hailer system to throw over a liferaft. I saw the men running up forward on my deck to go for the liferaft, and they threw a liferaft over the side which inflated right beside the men in the water. No effort was made by any man in the water to grab hold of the liferaft. No effort was made by any of the men in the water. No apparent effort was made by any of the men in the water to reach the lines which my men had been throwing to them after the boat capsized. I saw a life ring with line attached landing close to the men clinging to the boat, and they didn't make any effort to reach the life ring. At this time there were some men drifting down my port side, but the lifeboat was still off the port quarter of the ship with two or three men clinging to it. It was close to my port propeller at this time, so I had to stop my port propeller in case the men got caught in it....I maneuvered the ship back around to an upwind position from the lifeboat and steamed down close to the lifeboat, the men and the lifejackets in the water. There was no sign of life at all. We could see all the men floating with their heads under the water, some of them with their arms outstretched, no sign of life, and the men on the deck were trying to pick up bodies

Death obviously in this case was caused by cold shock and possibly swimming failure, but certainly not hypothermia.

Breath Holding Ability and Ability to Control Breathing Rate

This is very critical for all who abandon ship into cold water. If they abandon dry shod into a liferaft, there is no problem. However, if they abandon ship into cold water, unless they are mentally and physically prepared for the cold shock, are protected with a survival suit, a lifejacket and a spray hood, they may drown in the immediate abandonment due to the inability to control breathing in the first three minutes of immersion. It is not just a problem of not being able to breath hold; if you are in choppy water, there is an inability to coordinate and control breathing with wave splash. This is a typical scenario for passengers on tourist vessels in Canada's lakes and rivers in spring and early summer.

Sterba et al (1979) (Reference 142) investigated breath holding capability of humans in water ranging from 15°C-35°C. They concluded that breath holding ability at 15°C was approximately 30% of the non-immersed values.

Hayward et al (1984) (Reference 74) showed clearly that there is an inverse relationship between water temperature and breath hold ability. Thus, for abandonment in 25°C water, average breath holding is 38 seconds, whereas for 15°C, 10°C and 5°C water it is 28, 24, and 19 seconds respectively. They concluded that breath holding time in water below 15°C was 25-50% of the presubmersion level. Their predictive curve was recently validated at the higher end of the scale by Cheung et al (2001) (Reference 35) in 25°C water following a breath holding experiment. Two hundred and twenty eight subjects participated and the average breath hold time was a mean of 39.8 ± 21.1 seconds.

Potential for Cardiac Arrhythmias

Tipton (1989) (Reference 153) had already documented the initial cardio-respiratory responses to immersion in cold water, i.e. the massive increase in heart rate and blood pressure within the first three minutes of immersion. Then in 1994, Tipton et al investigated the cardiac responses to submersion in water of 5°C and 10°C (Reference 157). Ectopic arrhythmias (irregular heartbeats) were observed in 11 of the 12 subjects in 29 of the 36 submersions. These occurred immediately after breaking of breath hold, i.e. just at the time after jumping into the water and having to take a breath. They were benign in most cases, (i.e. they were of short duration, supraventricular in origin and producing

no symptoms). However, this may not be the case for an aging population of tourists that may have to abandon a vessel in cold water, such as the St. Lawrence River or one of the Great Lakes. For those with a potential heart conduction defect, the heart is likely to be very susceptible to sudden immersion in water of 10°C, resulting in a cardiac arrest or death. Sudden immersion in cold water to the neck makes the heart much more susceptible to arrythmias, due to an increase in output of the stress hormones (i.e. Adrenaline, Noradrenaline). The frequency of these arrhythmias is higher when the face is immersed.

Manual Dexterity

There has now been more research done on loss of tactility in cold water during the first 10-15 minutes of immersion (Reference 78). During this time, the cold water renders the limbs useless, and particularly the hands. It can become impossible to carry out any self-rescue procedures. This only enhances the possibility of perishing before hypothermia is established.

The ability to do such tasks as activate the life jacket inflation device (if fitted), climb into a life raft, cling to a becketted line or activate a flare depends on manual dexterity and grip strength. The ability of muscle to produce force is reduced when its temperature falls below 27°C. This can occur in as little as 20 minutes in water at 12°C (Reference 16). Vincent and Tipton (1988) (Reference 151) showed that the maximum voluntary grip strength (MVGS) of subjects who immersed their unprotected hands or forearms in 5°C water was reduced by 16% and 13% respectively, and that wearing a glove significantly reduced the MVGS by 16% in air and with the hand glove and water immersion combination, the reduction was 31%. Research has also shown that hand grip strength was reduced by up to 60% (References 36, 37, 60 and 81), manual dexterity was reduced by 30% (References 48, 95 and 148) and speed of finger flexion was decreased by 15-25%. A recent study by Heuss et al (1995) (Reference 78) identified minimum hand temperature criteria for safety and performance – local skin temperature 15°C, nerve temperature 20°C and muscle temperature 28°C.

The sinking of the Hudson Transport on Christmas Day 1981 in the freezing water off the Gulf of St. Lawrence is a classic example where cold extremities contributed to the death of five seamen (Reference 80).

> The raft was overcrowded. The night was pitch black. The deck lights had gone out a short time before. They could hear air escaping. They could feel freezing water coming up around them. A spirit of sauve qui peut seized them all. Six men made it back to the deck. They were helped by the captain and Kennedy to scramble up the ship's side. Their desperate plight may be imagined from the fact that some of them were so chilled by wind and water that they climbed the ladder using knees and elbows rather than hands and feet. Five others fell into the sea and were lost. Perhaps some of them were simply too cold to be able to climb up the ladder

Should Passengers Wear Lifejackets Prior To Abandonment?

This question was raised after several rapid sinkings occurred. Particular accidents cited have been the loss of the MV George Prince (1976) (Reference 163) in the Mississippi River where 76 people died, the loss of the USCG Cuyahoga (1978) (Reference 164) in Chesapeake Bay where 11 people died; the loss of the Marchioness (1989) (Reference 105) in the River Thames, UK, where 51 people died; and the loss of the MV Miss Majestic (1999) (Reference 165) on Lake Hamilton, Arkansas where 13 people died. The problem in each of these accidents was that many of the people were trapped between decks. The wearing of an inherently buoyant lifejacket would have further hampered their escape if it was possible. Nevertheless, for those who found themselves in the water and in the dark in two of the accidents, a lifejacket was critical to their survival.

If one is therefore going to regulate that passengers must wear a lifejacket on a passenger-carrying vessel that does not have the ability to carry a liferaft, then the lifejacket must be an inflatable one. The modern inflatable lifejacket is an excellent piece of life-saving equipment; it is comfortable, unobtrusive and very reliable. The Europeans have been using them for recreation and commercial boating operations on their lakes, rivers and canals for years. Canada has simply been slow in effecting new legislation for approval and it is only in the last five years that they have started to come into general use.

The argument from ship's operators that they are expensive to purchase and maintain is only partially true. The fact is that once operators start to use them and passengers become familiar with them, then the confidence in their merit will go up, the price (due to a higher demand) will go down, and maintenance costs will correspondingly go down due to the general public starting to respect a very good piece of equipment that will potentially save their life. The two children in the True North II accident would have likely been alive and well today if they had worn a good inflatable lifejacket as they stepped on board the boat.

Summary of Chapter 1

This chapter discusses essentials to know about the applied physiology of a sudden cold water immersion accident.

- Up until fifty years ago, no one really understood the reason why people suddenly immersed in cold water died. It was attributed to an inability to stay afloat and vague terms such as "exposure". Nor was anyone particularly concerned about the steady cost of life. It was simply accepted as an occupational hazard and fate.
- Any early attempt at saving ship wrecked mariners was to provide them with flotation in rather than out of the water.

- Death may occur from one of the four stages of immersion:
    - Stage 1 Cold shock (3 – 5 minutes)
    - Stage 2 Swimming failure (3-30 minutes)
    - Stage 3: Hypothermia (after 30 minutes)
    - Stage 4: Post rescue collapse (during or hours after rescue)

- Although the four stages have been known since World War II, stages 1 and 2 were considered only of academic interest. As a result, regulators, teaching establishments and survival suit manufacturers all concentrated their efforts on protecting the human from hypothermia. Indeed, in this regard they have done a very good job.
- Even though there are well established teaching programs, good regulations and much improved life saving equipment, there are still in the order of 140 000 open water deaths each year. What has been overlooked is the significance of the first two stages - cold shock and swimming failure as a cause of death. The severity of the effects of cold shock is directly proportional to the water temperature peaking between 10-15°C.
- The layperson and accident investigators are often surprised that some people do not survive a lengthy immersion. Theoretically they are within the "safe" boundaries of one or more of the survival curves that have been developed to predict death from hypothermia. These people do not die of hypothermia per se. They die from a variety of problems in which moderate hypothermia is enough for them to lose their physical ability and mental determination to keep their backs to the waves. Thus, they inhale the next wave and die from drowning in spite of wearing a life jacket.
- From all the combined research on cold water accidents and scientific research, it has become clear that sudden immersion in cold water, i.e. below 15°C is very dangerous, it should be avoided if at all possible. It has now been shown that a person's swimming ability in warm water bears no relationship to that in cold water. A conscious decision to swim (and rescue oneself) or stay floating still in the water (and be rescued) should not be taken lightly without assessing the pros and cons. In water below 15°C, crew and passengers must abandon ship dry shod. If it is not practical to stow a liferaft on small vessels, then passengers must wear a modern inflatable lifejacket at all times.

Chapter 2

HOW CAN WE PROTECT FROM THE FOUR PHYSILOGICAL STAGES OF COLD WATER IMMERSION

Introduction

For the reader who has skipped Chapter 1 and moved straight into this chapter, the four physiological stages are: cold shock, swimming failure, hypothermia and post rescue collapse. The basic principle of protection is to prevent contact of the cold water with the skin. The areas of the body that are particularly important with regard to cooling on immersion in water are, for different reasons, the head, back of torso and limbs. The head has only a weak vasoconstrictor response, thus blood continues to perfuse this area even in the cold. Consequently, a lot of heat can be lost from the head and when unprotected it can be a major route of heat loss. Head immersion can significantly accelerate the rate of fall of deep body temperature and the onset of hypothermia (Froese and Burton (1957), (Reference 46). The combination of reduced blood flow to the extremities and the horizontal flotation angle adopted in the water when most immersion suits are worn, results in the greatest percentage of heat loss occurring through the back of the torso by conduction. One reason for this is that the hydrostatic compression of the suit can reduce insulation in this area (Tipton and Balmi, 1996) (Reference 159). Due to peripheral vasoconstriction, relatively little heat is lost from the core of the body via the limbs when the body is cooled. However, one consequence of the reduction in blood flow to the extremities is that local tissue temperature in these areas falls and neuromuscular function can be quickly impaired. Survival can then be compromised by the inability to use the hands for essential survival actions such as boarding life rafts, deploying life jackets or firing flares (Tipton and Vincent, 1988) (Reference 151).

For the layman who may not appreciate the severity of being immersed in icy water, the sinking of the Empress of Ireland in 1914 in under 14 minutes off Rimouski in the Gulf of St. Laurence paints a dreadful picture.

> The ship sank, as she did so, a great and terrible cry arose from 700 throats. Where the ship had been was a struggling mass of men, women and children "as thick as bees" Those who had lifejackets found themselves dragged down by those who had not... The scenes below decks (of the Storstad that had collided with the Empress of Ireland, but remained afloat to conduct the rescue), defied description, 1012 perished.
>
> Drawn by a desperate search for warmth, hundreds of survivors crowded into the engine and boiler rooms. Some of them leaned against the cylinders until their flesh blistered. Women, shuddering with cold, tried to dry their scraps of nightdresses. Many of them were so frozen that they could not even remove what little clothing they were wearing. Mrs Andersen had to undress them and put on their numbed bodies whatever garments she could find. Then the women were packed into the Norwegian seamen's narrow bunks two by two, head to toe like herrings in a can, to warm each other back to life. (Croall, 1978) (Reference 38)

The immediate solution that springs to mind is that practically speaking, it should be possible to enclose the body of a person up to the neck in some form of water tight or semi water tight garment or enclosure to prevent the cold responses. This is precisely the approach that has been taken to date. Indeed, the British Merchant Advisory Committee had known this since 1922, yet had done little about it (Reference 112).

The personal garment has under gone a whole series of name changes over the years: anti-exposure suit, immersion suit, marine abandonment suit, poopy suit, and survival suit. In this report it will always be referred to as an immersion suit, except where it has been used by authors to describe either a specific physiological experiment or marine accident report in their own literature.

At opposite ends of the world, two accidents occurred within a day of each other only recently. They emphasize that a personal immersion suit is just as necessary today in the 21st century as when humans took to the water thousands of years ago. As in Chapter 1, other accidents that occurred more recently will be discussed later to emphasize specific problems.

10 Reported Dead in Ferry Sinking (Oslo) (Halifax Chronicle Herald, November 27, 1999)

Ten people died and another 11 were missing and feared drowned after an ultra-modern Norwegian ferry sank in chilly, rough seas off western Norway on Friday.

Hopes of finding any of the missing alive were fading hours after the sleek Sleipner catamaran, with 88 people aboard, went down in the North Sea after hitting rocks near Haugesund in stormy weather after nightfall.

Ferry Founders off China (Halifax Chronicle Herald, November 26, 1999)

On Thursday, more than 24 hours after the ship's first distress call, just 36 people had been rescued from the cold seas after sinking of the 9000 tonne Dashun ferry which carried 312 passengers and crew.

A similar catastrophe to either of these could easily occur to Canadian ferries, for instance on the run between Sydney, Nova Scotia and Newfoundland, or, Yarmouth, Nova Scotia and Bar Harbor, Maine. Currently with no protection, similar death rates can be predicted. The crew and passengers in the William Carson had a very close call in June 1977. The ferry en route to Goose Bay was holed by ice and sank very rapidly off St. Anthony's, Newfoundland. Miraculously, all 128 ship's company and passengers made an orderly and safe escape into the lifeboats in the dark (Reference 145).

Physiological Studies Conducted in Europe and North America 1939 - 1945

During the Second World War, none of the Navies on the Allied or Axis side wore immersion suits. Therefore, it is not surprising that the Talbot Report (1946) (Reference 147) and McCance et al's report (1956) (Reference 108) showed that between 30-40,000 sailors had simply drowned while escaping from the ship, i.e. during the survival phase. During the War, T.E. Metcalfe had invented a simple exposure suit for merchant sailors. By 1944, over 300,000 had been produced (Reference 22). Too often the suits went missing when required because there were often used for purposes for which they were never intended, i.e. painting ship. They were too flimsy for prolonged wear and were only meant to be used once in the liferaft and not during the abandonment into the water. Practically speaking, they probably made very little difference to the overall gloomy survival statistics. Macintosh and Pask (1957) (Reference 107) conducted their then secret pioneering work on the performance of lifejackets, but the fruits of their efforts were not realized in lifejacket improvements until well after hostilities ceased in the 1948 SOLAS standard and the 1963 BSI standard.

As mentioned in Chapter 1 under the post rescue collapse section, the Germans noted the terrible loss of critical personnel in sudden cold water immersion accidents. The sinking of the Bismarck and loss of airmen who bailed out alive and well into the cold North Sea during the Battle of Britain caused their physiologists and aviation medicine physicians to examine the problem. They commenced a large Research and Development program, which in part was the cause for the infamous Dachau experiments (Matthes, 1946) (Reference 109) and (Alexander, 1946) (Reference 4). They were the first to observe the "after drop" or continuation in reduction of body core temperature after being withdrawn from the cold water. They also experimented with survival suits and the Deutsches Textilforschunginstitut in München-Gladbach, ingeniously produced one that provided the insulation using soap bubbles (Alexander, 1946) (Reference 4), which appears to have gone into limited service (Reference 147).

Across the Atlantic during the Second World War, Canada, under the initial leadership of Professor Banting at the RCAF Institute of Aviation Medicine in Toronto was active in the research and development of an immersion suit for the Navy and Airforce. In 1941, Gagge, Burton and Bazett were having trouble explaining to the soldiers, sailors and airmen how much insulation to add or subtract to their clothing depending on the outside air temperature, their level of exercise / work and whether they were resting or not. They conceived the unit of Clo as a measure of clothing insulation, which could be used by heating engineers, physicians and physiologists (Gagge, et al, 1941) (Reference 47). It is defined as 0.155°C.m2.W-1, and is the insulation required to maintain comfort when a resting human is in an environment of 21°C, 50% relative humidity and with an air movement of 0.1 metres second-1. The European equivalent to a Clo used for sleeping bags and duvets insulation is the tog, which is 0.645 Clo. Clo value and its measurement will be discussed later in the report.

$$1\ \text{Clo} = 0.155^{\circ}\text{C.m2.W}^{-1}$$
$$1\ \text{Tog} = 0.645\ \text{Clo}$$
$$0.1^{\circ}\text{C.m2.W}^{-1}.$$

Probably the largest equipment trial ever to be conducted was carried out on behalf of the Royal Navy in 1943 by the Royal Canadian Navy in Halifax, Nova Scotia. Surgeon Captain Best from the RCN Medical Research Unit (who in collaboration with Banting had discovered insulin in 1921) managed the huge project and the US Navy provided additional ships and American personnel as subjects (Reference 24). All of the often conflicting requirements that face designers of immersion suits today, and difficulties in providing them, were identified, including lightness, simplicity, wrist and neck seals, zips, closure and drawstrings, ease of donning, addition of gloves or not and flammability were noted (Hiscock, 1980) (Reference 79).

In 1942, Frankenstein's in the UK had developed a leather immersion suit for the Hurricane pilots protecting the Murmansk convoys who were forced to ditch in near freezing water after launching because there were no aircraft recovery systems. Count Morner in Sweden (Reference 116) also invented a survival suit for merchant seamen during the war, but generally the principle throughout the world was to float survivors in rather than on the water, hence the grim survival statistics. By the end of the War, the Royal Canadian Air Force had developed an immersion suit for their ferry pilots (Figure 15) that went into limited service.

The US Navy was much slower in evaluating the requirement for immersion suits, because they did not join the war until later, and their operations, particularly against the Japanese were in relatively warm water, whereas the British, Canadian, and German operations were in sea water that rarely rose above 15-16°C, and for many months of the year was below 10°C. Another reason, was that their operational staff was still not convinced of the lethal effect of suddenly immersing humans in cold water. Therefore, funds and staff for R&D were slow in coming; so, they made only slow progress during the war. Important, however was the realization by Spealman (1944) (References 138) and Newburgh (1968) (Reference 119) of the dangers of hypothermia caused by cold water immersion.

All the initial, practical work in the US was done by LCdr. Hiscock in the Emergency Rescue Equipment Section (ERE). All the scientific work was done under the leadership of Dr. Newburgh at the NMRI in Bethesda. At the ERE liaison meeting in June 1943, the minutes reflected the fact that "lifesaving suits" had proved to be dangerous. The committee recommended that they be replaced by the "protective exposure suit" developed for the US Coast Guard by the B.F. Goodrich Company. This, according to Hiscock was the first reference by the committee to exposure suits for naval and merchant seamen. At the ERE conference in August 1943, the recommendations were that the immediate requirements of the suit were:

- As light as possible, for the least amount of bulk
- As simple as possible, without watertight zippers
- The hands must be free, with adequate wrist closures
- Could be used with a separate flotation jacket underneath; and could be stowed on the back of a lifevest or jacket (Reference 79)

Yet, typically after the war, all this research was shelved and no further work was done to protect the sailor or merchant seamen.

The ERE section was transferred to the Air Sea Rescue organization in 1944. Although an improved kapok life jacket was introduced into the Coastguard as a result of their work (Reference 3), it would appear in the US that immersion suits were commercially produced in very few numbers for the remainder of the war.

Physiological Studies Conducted in Europe and North America 1945 – 1970

The massive loss of life at sea during the War triggered several countries into investigating the problem. This section describes many of the different experiments that were conducted to explore the problems. It will illustrate:

- the range of investigations
- different concepts and design of suits
- subjects tended to be of white European or North American stock
- divers were often used as subjects, and they tended to already be cold acclimatized
- that experiments were done in calm or calm stirred water
- the lack of women as experimental subjects
- the lack of very large numbers of male subjects in each experiment
- that all the subjects were basically young, fit and healthy
- the wide range of water temperatures examined
- initial difficulty with procuring reliable, waterproof zips
- recurrent difficulty with keeping the suits waterproof
- quality control when prototype suits were massed produced
- little standardized experimental protocols, thus making it very difficult to make direct comparisons from one investigator's experiment to another one.

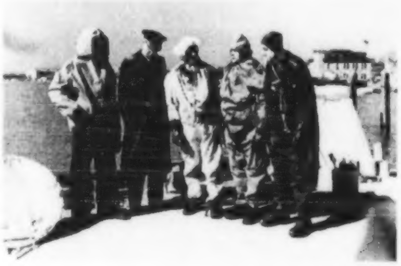
It was the Air Forces of the world that led the way. It was not until 1983 that the commercial marine industry and international regulators adopted an immersion suit standard through the International Maritime Organization. In all the experiments the requirements for an immersion suit were:

- It should be lightweight and easy to don
- It should be waterproof, but the fabric must be suitable for constant wear (i.e. breathable)
- It should be compatible with other equipment such as lifejackets.
- It should not hinder the ability to conduct essential survival actions when in the water, and it should be possible to swim in it.
- It should be ergonomically designed to fit a wide range of the population.

In fact, the majority of experiments were done in a back to front fashion. The suits were tested on various humans, then the conclusion was made that a human could predictably survive a certain time in that water temperature with that specific type of suit (Figure 7).

As we enter the 21st Century and more and more reports are stored in databases or websites, many of the earlier reports have either been forgotten or thrown out to make more space, or because they were more than 25 years old. Already some of this early work has been lost forever. (McCance's depositions, Lee's lifejacket work). The author makes no excuse for the length of the next two sections. This holds the key to the basic research and without this being documented in its entirety, new scientists will find it impossible to understand how the research and development was conducted.

Figure 7: **Early Post-war immersion suit trials by the US Coast Guard (Don't these suits still look familiar!)**



In 1946, Newburgh, Spealman and Van Dilla identified the physical problems of protecting the hands in cold water (References 119 and 139) but as mentioned above, work did not accelerate in the US until after the start of the Korean War.

In the meantime, in the UK, the Medical Research Council funded a large series of experiments that were conducted under the auspices of the Royal Navy Personnel Research Committee. This resulted in a thorough analysis of the problem in many laboratories and culminated in a whole series of field trials. From this work the once-only ship abandonment suit, the new RFD inflatable pattern No. 5580 life jacket and the first submarine escape suits were developed for the Royal Navy. In parallel with this, the Royal Air Force developed the Mk 1 through Mk 8 aircrew constant wear immersion suit. The first six Mks were made from neoprene nylon, and from 1951, the Mk 7 onwards was made from ventile fabric, invented by the Shirley Institute just post war. The novelty of the fabric was that it was woven from Egyptian cotton in such a way that it would allow body moisture (i.e. water vapour) to pass through the interstices of the fabric, yet when immersed, the cotton fibres would swell to produce a waterproof garment. In practice, it was found that suits had to be made from two layers of fabric to prevent the hydrostatic force of the water pushing its way through a single layer of fabric before the fabric had time to swell (Reference 172). Other disappointments were that it was very expensive to manufacture, expensive and labour intensive to construct the suits, and the fibres would not swell effectively when exposed to body sweat or greases. After the Mk 8 suits, all subsequent ones were manufactured as one-piece suits.

Across the Atlantic in the US, Bradner in 1951 used neoprene foam for immersion suits for the first time (Reference 19). In 1952, the US Navy formally recognized that their life saving equipment during World War II had been inadequate (Reference 167). They commenced a large R&D project over the next 15 years to find a survival suit for their sailors and a constant wear immersion suit for their naval aviators flying over cold water. The principal work was led by Newburgh who reported his findings in his textbook, Physiology of Heat Regulation and the Science of Clothing (Reference 119). A major trial by the USN in 1955 of eight versions of three immersion suits did not result in the production of a good suit (Reference 166). The USAF also noted losses in cold water off Korea and their work was led by Hall and his colleagues at Wright Patterson AFB. They used the thermal manikin extensively with the US Navy and the US Army Research Institute of Environmental Medicine. Typical manikin results by Bogart et al (Reference 25) in 1966 are listed in Table 1.

Table 1: **Immersed Clo values for ten suits tested at USARIEM in 1966**

Ensemble	Immersed Clo w/o head
Unisuit with Arctic Explorer Undergarment	1.34
Viking with Grey Foam Undergarment	0.87
O'Neill Supersuit with Blue Fluff Undergarment	1.27
White Stag with Neoprene Shorty	1.11
Unisuit with 2 sets Arctic Explorer Undergarments	1.55
Viking with O'Neill Blue Fluff Undergarment	0.73
Unisuit with Foam Undergarment (Viking)	1.38
O'Neill Supersuit with Navy Waffle Undergarment	0.96
Unisuit with Spacer Garment	1.13
O'Neill Supersuit with Spacer Garment	1.07

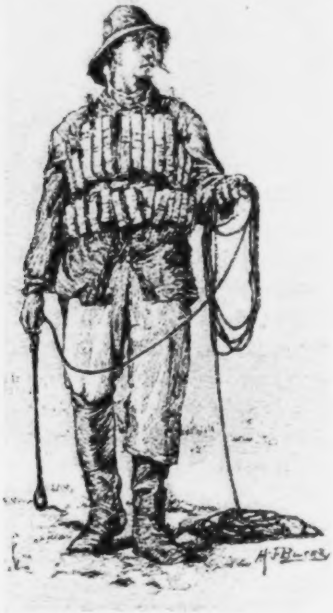
The most important work was reported by: Hall et al (1954, 1956, 1958) (References 61, 62 and 63), Beckman et al (1966) (Reference 19), Hall & Polte (1960) (Reference 64), and Goldman et al (1966) (Reference 58). There were four practical findings that came out of their work for the designers of immersion suits:

(a) suits lost 57% of their insulation through hydrostatic squeeze when the human was immersed to the neck
(b) a leakage of as little as a litre of water into the suit reduced the insulation by 22%
(c) maximal body insulation, which is approximately 4 Clo per inch thickness of fabric does not significantly prevent the hands from cooling down
(d) it was possible to categorize of all the different survival equipment by their Clo or insulation value and prescribe different Clo values for different operations

About 1960, the US Naval aviators had discarded their Mk 4 dry suit consisting of a rubber coated outer shell, a quilted insulation liner and elastic wrist and neck seals for a Mk 5 suit. This had a split zippered neck seal and an air ventilation system for cooling. This was followed in the late 1960s by a CWU-9P wet suit system (Reference 103).

Of all the occupations that require protection particularly from cold shock, swimming failure and hypothermia, professional fisherman are most at risk. Fishing garments have not changed for many years (Figure 8). In 1966 both Schilling (Reference 135) and Newhouse (Reference 120) observed chronic fatigue, contact dermatitis and a high mortality due to drowning from being washed overboard in high seas. Between 1959 and 1963, deaths in the British trawling industry averaged one person every six weeks. In 1970, a combined team of the Trade Union Congress, the Medical Research Council, the RAF Institute of Aviation Medicine and the Army Personnel Research Establishment proposed a new light, warm, wet proof, well fitting garment that was positively buoyant and reasonably priced (Newhouse, 1970) (Reference 121).

Figure 8: A sketch made by M.J. Burns of typical rig worn by fishermen and the US Lifesaving Service in the 1880s. (Photo courtesy of US Coast Guard)



There are a number of other important scientific papers related to this work from the UK and Canada on immersion suits and life jackets that were published during this period. Allen in Toronto unsuccessfully tried to find a replacement for the RCAF anti-ditching suit (Reference 10); Baskerville reviewed the status of protective clothing for the RN aviators (Reference 18); Crockford commenced his work on finding replacement protective clothing for the fisherman (Reference 39); Glaser and McCance reported on the first Arctic trial of RN protective clothing (Reference 52); MacIntosh and Pask were finally allowed to publish their previously secret pioneering lifejacket work form the Second World War (Reference 107); and Pugh et al published their work on the RN submarine escape suit (Reference 131).

Major publications which should be essential reading for all involved in the design and development of immersion suits and survival training published as a result of this twenty five years of research include:

Man in a Cold Environment (Burton & Edholm, 1955) (Reference 31)
Survival in Cold Water (Keatinge, 1969) (Reference 92)
Safety and Survival at Sea (Lee and Lee, 1989) (Reference 98)
The Hazards to Men in Ships Lost at Sea (McCance, 1956) (Reference 108)
Physiology of Heat Regulation and Science of Clothing (Newburgh, 1968) (Reference 119)
Survival at Sea (Smith, 1976) (Reference 136)

Practical Immersion Suit Trials 1970 – 1980

By the beginning of the 1970s, the general opinion was that hypothermia was the principal threat from sudden cold water immersion and that the best protection was a dry suit. However, manufacturers found it difficult to mass produce immersion suits for constant wear that were affordable. Good quality waterproof zips were expensive and cheaper alternatives did not work, quality control on the production of the suits was poor, so even brand new suits leaked. The only alternative to the neoprene or chloroprene coated fabrics was ventile fabric and as previously mentioned, this was expensive to manufacture and assemble into suits. With the difficulty of making a truly dry suit and facing the consequences of it being too hot and uncomfortable for constant wear, thoughts were given to producing wet suits.

It is important for the reader to have a definition of what is a dry suit and what is a wet suit.

(a) A dry suit is designed to function by keeping the insulation worn beneath it dry. This is achieved by the use of water tight seals, zips and impermeable material. A dry suit may or may not have insulation (insulated and uninsulated suits).

(b) A wet suit should be a close fitting garment which functions by trapping a layer of water next to the skin. This allows only a small volume of water to enter the skin / suit interface. This is warmed and does not have a significant effect on the inherent insulation provided by the suit.

In this ten year period, a whole series of immersion suits experiments took place in Australia, Canada, Finland, the Netherlands, Norway, Sweden, the UK and the US – basically countries where marine operators were working in cold water. Unfortunately, there has never been a true international joint commercial-military project to develop a suit, much of the work has been disjointed as can be seen in this and subsequent paragraphs. Riegel evaluated a whole series of suits over the winter of 1973 for the US Coast Guard. His protocol in Table 2 is an excellent model for all researchers to use (Reference 132). Crockford continued to improve the UK fishermen's work dress (Reference 40); Millward evaluated several suits for the UK fishing protection officers (Reference 114); Hampton evaluated the latest immersion suits for helicopter pilots flying for the UK offshore oil industry (Reference 66) and Werenkskiold evaluated the newer immersion suits at the Norwegian Ship Institute (Reference 171). Goldman continued to work with humans and the manikin on survival problems for the USAF, Army and Navy (Reference 59); Johansson evaluated a very large number of 20 immersion suits for the US Naval aviators (Reference 86). Hall predicted survival times wearing immersion suits in a life raft (Reference 65) and across the other side of the world, White conducted immersion suit trials to find a replacement suits for the Australian military pilots flying over the Bass Straights to Tasmania (Reference 173).

Table 2: **Summary of Suit Evaluation Data**

	Imperial	QD-1 Plus Preserver	Empress	Deck Suit
Tolerance Time, hr	14	2.2	2.4	5.8
Face-Up Float Stability	Yes	Yes	Yes	Yes
Self-Righting Capability	No	Yes	No	No
Freeboard (inches)	3.5	5.5	3.5	3.6
Donning Time, min.	0.89	1.3	0.6	0.9
Color Orange or Yellow	Yes	Yes	Yes	Yes
Retroreflective	No	No	No	Yes
Stowage Vol., ft3	1	0.8	0.1	1
Maintenance Freq., yr	5	5	5	5
Cost	$75	$120	$125	$100
Walk Speed, ft/min	333	370	357	333
Climb Ladder, ft/min	77	91	100	91
Can Emerge from Water	Yes	Yes	Yes	Yes

The offshore oil industry was also keen to procure the best ship abandonment immersion suits and helicopter crew and passengers suits. In 1978, Hayward et al from the University of Victoria, British Columbia, conducted the largest immersion suit human physiology trial so far performed in Canada (Reference 72). They evaluated 23 different military and civilian suits. The suits fell into three distinct categories: dry with closed cell foam - dry without foam, and wet with closed cell foam. All twenty subjects were immersed for 2-3 hours in ocean water at 11.8°C off Banfield, B.C. These suits represented the current state of the art twenty-four years ago, and are listed in Table 3.

Table 3: Evaluation of twenty-three military and civilian immersion suits.

Design-Concept	Suit Code (Series and number)	Suit name	Country of manufacture
Dry, without foam (D)	D 1	Beaufort Quick-donning	England
	D 2	Jeltek "Seacheater"	England
	D 3	CWU-16/P	US
	D 4	Beaufort Ventile Mk 10	England
	D 5	Hansen Ventile	Denmark
	D 6	ILC Dover (AE1)	US
	D 7	Multifabs	England
Dry, with foam (DF)	DF 1	Bayley	US
	DF 2	Fitz-Wright	Canada
	DF 3	Imperial	US
	DF 4	SIDEP "Seastep"	France
	DF 5	Multifabs (foam model)	England
	DF 6	Helly-Hansen (D600-0)	Norway
Wet, with foam (WF)	WF 1	Imperial (model H)	US
	WF 2	Imperial (flight)	US
	WF 3	Harvey's	US
	WF 4	CWU-33/P (long-sleeve)	US
	WF 5	CWU-33/P (short-sleeve)	US
	WF 6	Mustang (model 175)	Canada
	WF 7	Wendyco "Norwester"	England
	WF 8	Mustang "UVic Thermofloat"	Canada
	WF 9	WF 8 plus "Sea-seat"	Canada
	WF 10	Fitz-Wright diver's	Canada
Control	C 1	No survival suit	

Not surprisingly, the human cooling rates in the suits fell into three categories too, the dry insulated suits having the slowest rate (0.31°C hr-1) and the dry uninsulated suits having the highest rate (1.07°C hr-1). From this work, Hayward et al. were able to compile a very useful guide as to the number of hours to reach three levels of hypothermia (27°C, 30°C, 33°C) when immersed in 8 - 11°C water.

Operational trials were conducted in realistic conditions to assess how long humans could survive in various wet or dry suits. The conclusions from each experiment revealed similar findings. In the early days, the quality control on the manufacture of suits was poor: many brand new suits leaked so badly that the subjects had to be physically lifted out of the water after only a short immersion; and some groups of people even refused to wear them. The quality and reliability of the early zips was poor and ventile fabric was not the success that everyone had hoped. It also became apparent, that to survive in North Atlantic type water, which rarely warmed up above 16°C and was often in the single digits, a dry suit was essential. Both manikin and human testing showed that even a small leak had a profound effect on reducing Clo values as did the effect of hydrostatic squeeze. Moreover, it was very difficult to keep the hands warm even with the maximum insulation worn on the body. Up until this time there was still no internationally recognized immersion suit standard.

There was also a much bigger customer demanding better suits and that was the offshore oil industry. Their sponsorship and funding were the key to the improvement in immersion suits over the next 20 years.

1980 – 2002: The Offshore Oil Industry Requires Immersion Suits

By 1980, a whole series of second generation suits were being manufactured and tested. These were principally being used by the now well developed offshore oil industry for both helicopter ditching and ship/rig abandonment. After the Alexander Kielland accident in 1980 and the sinking of the MS Malmi, the Norwegians and Finns evaluated a number of suits with now familiar names such as: Aqua Suit, Bayley, Beaufort, Fitz-Wright, Helly-Hansen, Imperial, Lifeguard, Liukko, Manu, Multifabs, Nokia, Nord 15 and Shipsafe (Reference 93).

Generally, there was still dissatisfaction with the suits and only too familiar comments:

- Flotation position was not satisfactory (too little freeboard)
- Small people nearly get lost in the suit after a five metre jump into the water
- Leakage on glove seal with suit
- One size suit does not fit everyone
- All zippers need regular maintenance
- Very difficult to swim in the suit
- Leakage into the suit, which in some cases caused great difficulty in boarding liferaft
- Poor durability of fabric
- Requirement for good maintenance

As described in Chapter 1, in 1981, Golden and Hervey published their classic work on the physiology of sudden cold water immersion (Reference 56). In 1983, the next major achievement was the ratification of the International Maritime Organization, SOLAS standard for insulated and uninsulated suits (Reference 85).

1986 was a prolific year for reports on survival suits, principally because the International Ergonomics Society held a conference in Helsinki on the specific topic of survival at sea and immersion suits. Hayes (Reference 68) from the RAF Institute of Aviation Medicine, provided a very clear and precise performance specification for an immersion suit at the meeting. The purpose of immersion protection clothing is to:

- Minimize the occurrence of cold shock
- Prevent hypothermia and non freezing cold injuries
- Reduce the likelihood of post rescue collapse
- In conjunction with personal flotation devices prevent drowning from wind and wave splash as well as from facial immersion

Avery and Light from RGIT, Aberdeen (Reference 13) discussed the problems of leak testing and demonstrated that "good" suits could leak between 145 and 1398 mls of water. Lotens and Havenith from TNO in the Netherlands (Reference 104), examined the ventilation of garments in an effort to improve the comfort of the dry suit. Pasche and Ilmarinen from the Institute of Occupational Health in Helsinki (Reference 129) reviewed the new temperature parameters introduced by the 1984 IMO committee and commented that from a safety point of view, more attention should be paid to skin temperature to prevent non-freezing cold injury; and from Canada, Mekjavik and Gaul from the Simon Fraser University, British Columbia (Reference 111) examined the heat stress produced by a typical immersion suit worn by pilots flying offshore and Sullivan and Mekjavik (Reference 144) examined the ventilation indices of the suits to improve comfort.

The remaining work presented at the conference in 1986 all came from the US. Steinmann et al from the US Coast Guard, (Reference 140) examined the effect of wave motion on the insulation properties of eight different suits. This was further amplified in a paper in the Aerospace Medical Journal (Reference 141). The water temperature was 11°C and eight volunteer Coast Guard crew were exposed to 4-6 foot swells with occasional four foot breaking waves and 2-3 foot wind waves. The dry suits performed better than the wet suits and the tighter fitting suits performed better than the loose fitting suits. They further concluded that survivors in rough seas may have a significantly greater risk of immersion hypothermia than previously assumed based on survival time projections from calm water studies.

Riley (Reference 133) also from the Coast Guard commented on the idiosyncrasies of the introduction of the new IMO standard. The fact was that an insulated immersion suit could be substituted for a lifejacket if the suit met all the performance standards of the lifejacket. He pointed out that the current buoyant immersion suits will not turn an unconscious person face up in the water. Kaufmann and Dejinika from the Naval Air Development Centre (Reference 88) reported on the successful use of Gortex immersion suits by 14 subjects aged 21 – 40 years in 7.2°C water.

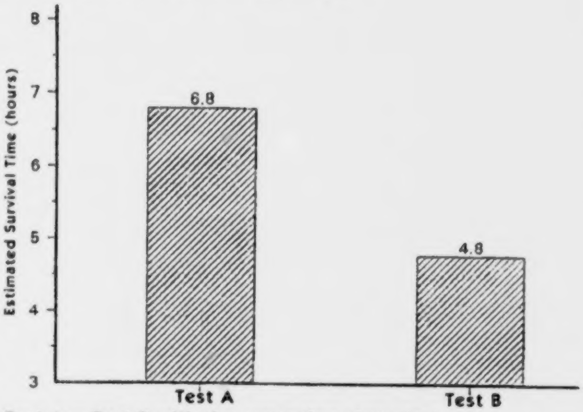
In the first five years of this period, several repeat experiments using newer fabrics such as Gortex and Thinsulate and new, waterproof zips were carried out. The findings reconfirmed the requirement for a dry suit, but the suit design essentially remained the same and there has only been a small gain in thermal performance, principally due to better overall waterproofing of the suits.

Allan et al. (References 8 and 9) re-visited the possibility of providing a wet suit for helicopter passengers, the object being to reduce the thermal discomfort of a constant wear suit. However, the shuttle jacket introduced into service by Shell was later withdrawn when Tipton et al (1989) (Reference 152) reported that it did not protect the passenger from the initial responses of immersion in cold water, i.e. cold shock.

As human testing became more expensive and human ethics committees less amenable to using humans simply to test suits to a specific standard, there was an increase in the use of thermal manikins to do this job. As a result of the Ocean Ranger accident in 1982 off the Grand Banks of Newfoundland, Canada introduced specific survival suit standards for ship abandonment suits (CGSB 1999) (Reference 34) and helicopter passenger suits (CGSB 1999) (Reference 33) in which the thermal test could be conducted with a manikin.

By now, it was being noted that the equipment in service both for the military and commercial operations had performed "surprisingly poorly" during real accidents. There are still about 140,000 open water deaths reported each year. How could this be when there is such a range of tests and regulations to theoretically prevent this? The answer is that many of the tests are innocuous and not realistic. The tests must either re-create the tasks that may have to be undertaken and / or the environmental conditions which may exist during the accident, or enable prediction of the decrement that will be seen in more adverse conditions. In 1995, Tipton (Reference 158) demonstrated this very clearly with a group of twelve subjects who undertook two immersions wearing identical clothing in two tests: Test A and B. However, in test B, simulated wind (6 knots), waves (15 cms) and rain (36L/hr) were introduced as well as a 15 second period of initial submersion. The estimated survival time was reduced from 6.8 hours in Test A to 4.8 hours in Test B (Figure 9).

Figure 9: Estimated survival time with and without simulated mild weather conditions.



Test A = Test B with the exception that wind, waves, simulated rain and an initial period of submersion were used in Test B

(Courtesy Journal of the R.N Medical Services)

The reader is directed to a number of scientific papers relevant to this period. Light et al (1980) (Reference 101) commenced a whole series of immersion studies at RGIT in Aberdeen for the offshore oil industry. Hampton from Leeds (1981) (Reference 65) reported more extensive tests on immersion suits for the offshore oil industry. Baker continued work on improving the RN submarine escape suit (1987 and 1988) (References 14 and 15). Hermann from the Institute of Occupational Medicine in Hamburg (1988) (Reference 75) cautioned the operators about the incompatibility of survival suits and lifejackets. After Allen (1964) (Reference 10) failed to find a good replacement immersion suit for the Canadian Airforce, Hynes et al from Defence and Civil Institute of Environmental medicine (DCIEM) (1985) (Reference 82) tested a whole series of new, improved garments. A new suit was finally chosen in 1989 by Sturgeon (Reference 143).

Ilmarinen et al (1981 and 1984) (References 83 and 84) tested a whole series of ship abandonment and helicopter passenger suits for the Finnish Board of Navigation and the offshore oil industry. Kaufman et al from the US Navy (1984) (Reference 87) reported data on the new Gortex material and Thinsulate liners. In Norway, Langhaug et al (1982) (Reference 93) continued work on evaluation of immersion suits and in Sweden, Larsson et al (1991) (Reference 94) suggested modifications to the RN Mk 8 submarine immersion suit. Pasche et al (1982 and 1984) (References 127 and 128) conducted a whole series of experiments on immersion suits at Nutec, Bergen, Norway and reported on the profound effect that leakage made on the insulation value. Romet et al from DCIEM, Toronto (1991) (Reference 134) compared the immersed Clo value of immersion suits measured on humans and on the CORD manikin.

Reviewing the practical immersion suit testing that has taken place since 1945, a general observation is that considerable expense in cost of duplication of technical equipment and materials has occurred over the last 45 years. Added to this, inter-service, inter-academia and international rivalry has slowed down the acquisition of knowledge of cold water physiology. An international military-commercial coordinated effort would have likely made more progress for less cost in less time, and saved stoical subjects some considerable discomfort over the years.

There are subtle reasons why progress was slow at the IMO working group. The first was that members chosen to attend were often not the most knowledgeable in cold water physiology and able to make the correct decisions; and many Nations arrived with a pre-conceived agenda driven by their national industry. As a result, many compromises had to be made. The only practical decision that was made was that a body core temperature of 35°C represented a case of hypothermia, therefore the insulation of the immersion suit should prevent a normothermic test subject from cooling more than 2°C in 2°C water after six hours immersion.

Summary of Chapter 2

This chapter discusses the practical aspects of trying to construct the best immersion suit.

- It took until the middle of the Second World War for the UK and Germany to realize that there was a problem from sudden cold water immersion. Up until 1945, there were only rudimentary suits in service; however, in 1941, Gagge et al had made the first step by defining the Clo value for clothing insulation.
- Post war research on survival statistics by the Talbot Committee and McCance et al revealed that the problem was more serious than originally imagined. The US military forces were not finally convinced that there was a problem until after the Korean war.
- Several critical scientific papers and textbooks are cited as mandatory reading for all students involved in survival at sea and its application to immersion suits such as the effects of leakage, the hydrostatic squeeze on the suit, Clo value and difficulty with protecting the hands.
- This realization spawned research principally in those maritime countries operating in cold water. The first generation of post war suits did not meet expectations, they were hot, bulky and leaked badly. Much of this was due to poor fabrics, unreliable wrist and neck seals, non-watertight zippers and poor quality control in the manufacturing process.
- By the mid 1980s, spurred by the IMO immersion suit standards and the offshore oil industry's demand for better quality, improvement in fabrics, insulating material, waterproof zips and better quality control, there was an improvement in the suit design and reliability. This is also reflected in the number of applied physiological papers cited during this period.
- Nevertheless, progress would have been more rapid if there had been international military-commercial resolve to investigate the problem sooner.

Chapter 3

KEY PHYSICAL ISSUES IN THE DESIGN AND TESTING OF IMMERSION SUITS

Specific Investigations into the Effects of Water Ingress (Leakage): Why it is So Important to Keep Dry?

Chapter 1 discussed the critical physical fact that water transfers heat away from the body approximately twenty five times more rapidly than air. However, because of the physiological responses evoked, humans only cool 2-5 times faster in water compared to air at the same temperature. Nevertheless, if the dry immersion suit leaks then there is a serious loss in its Clo or insulation value. In 1956, Hall and Polte (Reference 62) were the first people to demonstrate this using a thermal manikin. For an average man of 1.8m, a leak of 1620 grams would produce a 50% reduction in insulation.

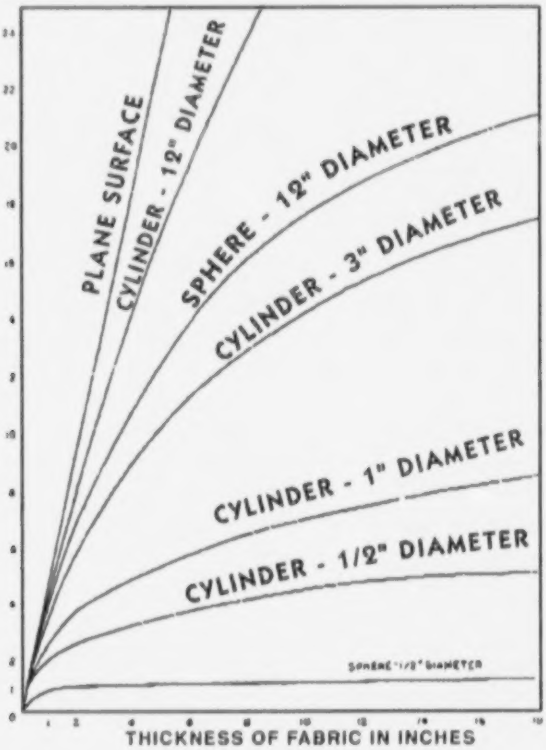
In 1984, this work was extended by Allan (References 6 and 7) and Allan et al in 1985 (Reference 8). They demonstrated that a leakage of as little as 500 grams of water into a dry suit reduced the insulation by 30%! They then prescribed a water ingress test specifically for testing immersion suits which was modified from the original 23 minute test described by Ernsting in 1966. The original test required the subject to jump into the swimming pool followed by three minutes of swimming and twenty minutes of passive flotation in a life jacket. The acceptable leakage after this time was 500 grams. In 1982, the allowable leakage was reduced to 200 grams. The reason for this was that a 500 gram leakage was probably acceptable for survival for one hour at 5°C, but not for longer periods. Allan's new test recommended a jump test followed by a twenty minute swim test or twenty minute test in a wave tank. The object being to ensure the water integrity of the closures of the suit and the wrist and neck seals (Reference 6). Unfortunately the manufacturers had still not grasped this important point; hence the quality control on the suits was still not good enough and suits continued to fail the thermal tests.

Why is it so Difficult to Keep the Fingers Warm?

The reasons for this have been superbly explained by Beckman et al in 1966 (Reference 18). in their review on the control of body heat loss in aircrew subjected to water immersion. This is quoted directly from their paper in Aerospace Medicine in April 1966 and summarized the pioneering work done by Newburgh, Spealman and Van Dilla in the 1940s (Reference 119).

Insulative values of materials are normally described in terms of flat surface insulation. Although the insulative value of material on a flat surface is directly related to its thickness, the relationship is not as simple on shapes like cylinders and spheres. The relationship of thickness of fabric in inches to the effective insulation in CLO is seen in Figure 10. On the bottom line of this graph it is seen that as the thickness of the insulative fabric surrounding a 1/2 inch sphere is linearly increased, the insulative value increased only slightly and no significant increase in insulative value is provided by increasing fabric thickness beyond 1 inch. The insulative effect of increasing the thickness of the insulative fabric around a cylinder of 1/2-inch diameter is only slightly better than for a sphere. This figure illustrates why it is difficult, if not impossible to provide adequate insulation for thin cylinders such as fingers and toes. It has long been known that it is almost impossible to provide adequate insulation in the form of gloves for the fingers and hands in extremely cold Arctic weather. For this reason, mittens rather than gloves have been provided so that the fingers and hands may be made into a ball to improve their surface [area] to mass ratio. A theoretical solution proposed by van Dilla, et al., to the problem of providing adequate insulation for Arctic troops in -50°C weather with a 30 knot wind are equal in magnitude to those of providing adequate thermal insulation for personnel immersed in freezing water.

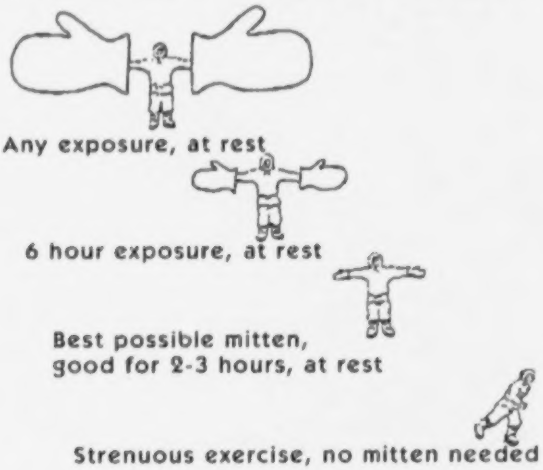
Figure 10: **Insulation of ideal fabric on a plane, cylinders and spheres.**



(After Van Dilla, Day and Siple in Newburgh - Physiology of Heat Regulation. 1968, Hafner Publishing Co.)

Because of these physical facts, it is very difficult to insulate the fingers. Van Dilla produced a simple figure (Figure 11) to show the relative size of the mitten required to insulate the hands under different work loads.

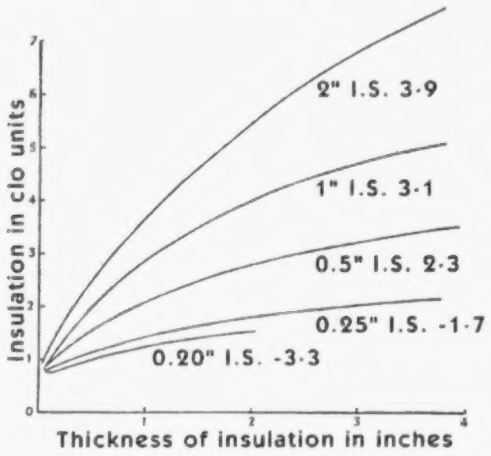
Figure 11: **Relative size of mittens needed for different exposure times at minus 20°F.**


Any exposure, at rest
6 hour exposure, at rest
Best possible mitten,
good for 2-3 hours, at rest
Strenuous exercise, no mitten needed

(After Van Dilla, Day and Siple in Newburgh Physiology of Heat Regulation. 1968, Hafner Publishing Co.)

Furthermore, Burton and Edholm (1955) (Reference 32), made the important comment that a fact know to ventilation engineers for many years was that insulating very narrow diameter cylinders actually caused a decrease in insulation value (Figure 12).

Figure 12: Regional Thermal Insulation



(After Burton, Edholm, Man in a Cold Environment)

Finally, Hall et al in 1954 (Reference 61) already noted that body insulation had little effect on hand cooling even when a maximum insulation of 4.7 Clo was worn. So bundling up has no effect unless one increases one's level of heat production by exercise as is so beautifully demonstrated in Figure 11.

Why do Dry Suits Feel Uncomfortable for Constant Wear?

Each day, even at rest, a human loses approximately 500-850 mls of fluid through the skin. This is called insensible sweating. It has not been unknown for Canadian Air Force Tracker pilots flying over cold northern water off Newfoundland in June, to empty 1 litre of sweat out of their constant wear immersion suits on return from a six hour fishing patrol. As a result the Royal Navy Institute of Naval Medicine currently evaluates constant wear suits with a six hour air exposure, 20°C light intermittent exercise, then thirty minute immersion in 4°C – it is possible to accumulate more than 1 litre of sweat in the feet of impermeable suits, but vapour permeable suits remain almost dry inside.

Unless the suit is well ventilated with open cuffs, neck seals and openings at the feet to assist in the removal of this hot, humid layer close to the skin, the suit becomes hot and unbearable. Berglund (1966) (Reference 23) reviewed the topic of thermal comfort and the effect of clothing. He noted that humans are very good at sensing skin moisture and that their perception of skin wettedness between dry and soaking wet has a high correlation to measured skin wettedness. How skin wettedness is sensed is still unknown. Important to note is that skin wettedness above 30% increases the friction between skin and clothing contributing further to discomfort.

It is beyond the scope of this report to discuss the physics of clothing. For more details, the reader is directed to the excellent NATO Research Study Group 7, Handbook of Clothing: Biomedical Effects of Military Clothing and Equipment Systems with individual papers by Goldman, Lotens and Vangaard (Reference 117).

The Effects of Wave Motion on Immersion Suit Insulation

The majority of the early testing of immersion suits was done in cold water tanks in which the water was gently stirred. This was principally because the research was being conducted in physiology departments of universities which did not have access to wave making machines or large pools. Although it had been known for a long time, probably Goldman et al in 1966 were the first to note and accurately record that there was a difference in the insulation of clothing in turbulent water compared to still water. The decrease in insulation of a wet suit when measured on the manikin was from 0.76 to 0.71 Clo (Reference 58). Then Steinmann et al (1987) demonstrated that the core cooling rate and decline in skin temperature of human subjects were significantly larger in rough water than calm water. Such differences were found for loose fitting wet suits, but not tight fitting wet suits or dry suits (Reference 141).

Later, in 1991 Romet et al (Reference 134) confirmed the Steinmann study by reporting a significant reduction of wet immersion suit insulation in turbulent conditions compared to still water by an average of 29.7% when measured on humans. In 1994, Sowood et al (Reference 137) reported a 30% reduction in dry suit insulation when tested on a manikin in 60cm waves compared to still water.

Then in 1995, Ducharme and Brooks (Reference 42) examined the effect of 70cm waves on the dry suit insulation of suits worn by humans. They concluded that the loss of insulation ranged from 14 – 17% on humans and 36% on manikins. They recommended that future mathematical models should recognize this fact, that thermal manikin design should more closely match the floating position of a human in the water and investigation should take place at greater wave heights. This subsequently happened, with the Canadian Navy sea trials off Halifax harbour in 1996. Six subjects were immersed in 2.5°C sea water in waves of two metres height. At the end of the immersion, the dry suits had an average insulation of 1.24 immersed Clo which was not significantly different to values obtained with the same suits in 60-70 cm waves. Thus, to date, until anyone conducts experiments in greater wave heights, the hypothesis is that the loss of 15% in suit insulation plateaus at about a one metre wave height (Reference 30).

How Much Buoyancy is Allowable in a Helicopter Crew or Passenger Suit?

Unique to the helicopter crew and passenger flying over water is the potential for ditching and rapid inversion of the aircraft. The current immersion suits all depend on trapped air in the layers of the suit to provide the thermal insulation. This in turn makes the suit highly buoyant. If, however, the suit is too buoyant, then it will be impossible to make an escape from a downed, inverted, flooded helicopter.

This problem was addressed by Brooks and Provencher in three experiments at DCIEM in 1984 (Reference 27). The first experiment determined how to measure the inherent buoyancy of an immersion suit when inverted underwater. This led to the invention of the underwater weighing chair specifically for this purpose; this is now standard equipment used in the 1999 Canadian General Standards Board helicopter passenger suit standard (Reference 33). The second experiment was conducted in the DCIEM Deep Diving Facility. This was mocked up to represent a flooded Sea King Helicopter passenger seat and emergency exit. The objective was to determine what was the maximum added buoyancy that would overcome the ability of a human sitting inverted in a ditched helicopter from releasing the seat harness and pulling him/herself out of an emergency hatch. Seven male clearance divers conducted the escapes basically dressed in a T-shirt and cotton trousers. After each successful escape, further buoyancy was added until the diver could not escape and had to simply remain in the inverted seat breathing from the diver's regulator. The results showed a very wide range of buoyancies, which caused problems. The failures occurred between 36 and 57 pounds of added buoyancy. It was established that the largest, strongest diver with the longest arm reach was physically pinned in the seat with 57 lbs of buoyancy. This set the absolute upper limit for buoyancy.

The third experiment was done in an open pool with the same divers (as controls) and also with non-divers. The objective was to investigate the effect of slightly more room to maneuver than in a diving chamber, and also to see if there was a difference for mixed gender non-divers of smaller stature and less upper body strength and shorter arms length. The divers did marginally better, the added buoyancy levels at which failure occurred ranged from 39 to 60 lbs. However, the non-divers were significantly more hampered by added buoyancy and failures occurred between 19 and 40 lbs. The principal difference being due to comfort level underwater, height, reach, upper body strength and shorter arms length. An initial limit of 20 lbs was established for the inherent buoyancy, but with this limit, the thermal requirement for the suit could not be met. Trials were then completed in the helicopter underwater escape trainer at Survival Systems Limited using the prototype suits built to the tentative new CGSB standard. All the students had no problem with escape with an inherent buoyancy of 35lbs. To assist the manufacturers to meet the thermal requirement, the initial standard of 35lbs (150 N) was finally established at 42 lbs (175N). This is a good example where groups involved in standards development resolved a practical issue.

Flotation Angle

As discussed previously, the ideal flotation angle is for the body to be resting at 45° to the oncoming waves. However, the additional buoyancy in the suits to protect from hypothermia prohibits this from happening. The majority of people adopt a horizontal position in the water (Figures 13 and 14). This problem has certainly been known since World War II; it was alluded to by Smith (Reference 136), but was not formally recognized until a presentation made by McDonald at the Robert Gordon Institute (RGIT) in 1983: "The overall buoyancy of a very large percentage of thermal protective suits negate the self-righting characteristics of approved life jackets. Suits with inherent buoyancy also show no potential for self-righting, indeed most are equally stable with the wearer face down or face up." Therefore, with this in mind only by integrating the whole system from the basic design can the flotation angle be improved in the next generation of suits.

Figure 13: **The problem of an incorrect flotation angle when wearing an immersion suit has been known at least since these tests at the RCAF Institution of Aviation Medicine, Toronto in 1944.**

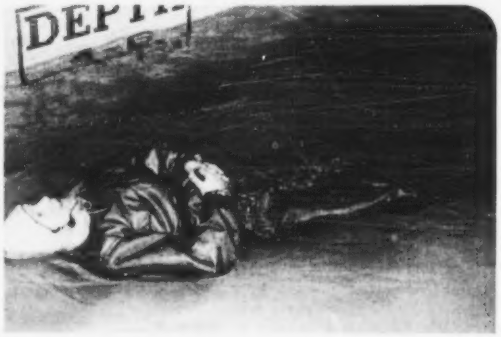
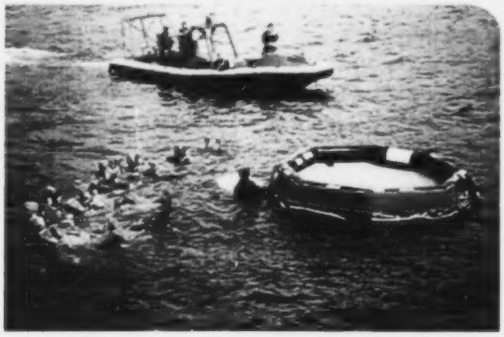


Figure 14: **A group of subjects in the Bergen Fjord (1986) who have completed a swim away procedure from the helicopter prior to liferaft entry. Note their floating position in the water.**



Measurement of Clothing Insulation

The measurement of insulation conceived by Gagge et al. in 1941(Reference 47) is the Clo value. This can be measured using humans or an immersion thermal manikin.

At its simplest, heat (H) flows from a place where the temperature is high (T1) to a place where it is low (T2) according to the relationship:

$$H = k(T_1 - T_2)$$

where k is a constant called conductance that represents the ease with which heat flows. The reciprocal of conductance (1/k) therefore represents the thermal resistance to heat flow or the insulation (I) of a material. Insulation can therefore be estimated using the equation:

$$I = \frac{T_1 - T_2}{H}$$

If T_1 is made to present skin/surface temperature and T_2 = suit surface/water temperature and H the heat being lost through the clothing, then the insulation of a clothing assembly can be calculated.

With a manikin, H is represented by the power supplied to the manikin. In humans metabolic heat production minus respiratory heat loss is assumed to represent the heat being lost from the body when body temperature is not changing (i.e. in steady state) (Tipton and Balmi, 1996) (Reference 159). If body temperature is falling this additional heat loss must be accounted for. Alternatively, sensors that measure heat flux can be placed on the surface of the body, under a suit, to measure the heat flowing from the body, through the clothing assembly and to the water (Bell et al, 1985) (Reference 21).

There are advantages and disadvantages associated with the use of both humans and manikins. For example, using humans carries medical and ethical responsibilities; failure to estimate or measure mean skin temperature, heat production and heat flux accurately introduces error, as does the estimation of changes in heat storage when deep body temperature is falling. In its favour, the human technique is more representative in terms of position in the water and fit of the suit; regional fluctuations in heat loss and insulation can be pinpointed subjectively ("it feels cold here") as well as objectively. Also, because a steady state is not required (falls in body temperature can be accounted for), the heat flux technique is quick and can be used to measure the effect of human movement such as swimming; the human technique also allows deep body temperature to be measured and thus insulation to be directly related to this variable.

The benefits associated with the use of manikins include avoidance of the medical and ethical consideration associated with human testing, easier logistics and greater reproducibility. Other advantages include:

(a) there is no limit to the number of times the manikin can be immersed in the water
(b) tests with manikins give accurate segmental insulation according to strict engineering principles:
(c) there is no limit on the temperature of the water
(d) the angle of the manikin in the water is consistent and so the Clo value for each suit is consistent and it is possible to do comparative tests between different suit designs
(e) the suits can be tested in greater than Beaufort 3 sea conditions[2]
(f) the cost of testing each suit is relatively inexpensive
(g) subtle improvements in suit design to improve Clo value can be observed on the manikin where many consistent tests can be done. These improvements cannot be observed on small numbers of humans with different physiological responses to the same conditions.
(h) All the cold thermal tests can be conducted on the manikin, yet the leak tests and ergonomic tests can still be done on the human in warm water.

Disadvantages of this method include the mistake that many people make of assuming that manikins react like humans. But, manikins do not react the same way as humans (they do not vasoconstrict, the generation and delivery, and therefore distribution of heat throughout the respective bodies differ). As a consequence, the results from manikins can be misinterpreted. Another weakness in the technique is that to relate the insulation measured on a manikin to alterations in deep body temperature requires the use of a mathematical model, with all the assumptions and limitations which that entails. More research is required to validate these assumptions.

Although we have come a long way in our knowledge, the three disadvantages to manikin testing are primarily related to the fact that the manikin is not articulated like a human and therefore does not ride the waves like a human. The manikin does not respire, nor need to keep the water clear of the oronasal cavity, and it does not vasoconstrict like a human. If these first two facts are examined closer, this means that the human in a flexible position at the surface of the water will tend to have more of the chest out of the water per unit time compared to the manikin. This results in less hydrostatic squeeze, particularly on the front of the suit, and to a lesser degree on the back of the suit. This in turn means that the results obtained from the manikin will be more pessimistic than for the humans. This in itself is not a particularly bad thing, because this means the manikin results will err on the safe side, but the downside to this is that a basically good suit which is close to the line on thermal protection may be failed when tested against a standard. Romet et al. (1991) (Reference 134) concluded there was no significant difference in Clo value of suits measured on humans or the manikin when in cold stirred water, but once waves were added, there were considerable inconsistencies.

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[2] Beaufort 3 sea conditions (wind speed: 7-10 Knots, 8-12 mph, 13-19km/h) Gentle Breeze: Leaves and twigs move around. Lightweight flags extend. Long wavelets, glassy sea crests.

This was recognized by Allan (1985) (Reference 5) when he originally persuaded the UK regulatory body to accept manikin testing over human testing. He was meeting resistance from the old die hards who did not wish to give up seeing six subjects sitting in 2°C water for six hours. He argued quite correctly that the results from a manikin test would in fact be more severe than the human test and err on the safe side. In other words, if the suit passed the test on the manikin, it would certainly pass the test on the thinnest human.

There is no doubt in the author's mind that it was a very good decision to introduce manikin testing in the Canadian immersion suit standards. As a result, the second generation of suits are far better designed and manufactured than the first generation and when well maintained do not leak. However, when it was introduced, funding was expected to continue to refine the thermal link between the manikin and a vasoconstricted human, unfortunately this did not happen. In the current system the Clo value from each segment is summed to provide an overall average, and it is this average that is used in the various specifications and standards around the world. However, the use of such an average wastes the segmental data and can be misleading. The potential for error arises when the results for overall average external insulation obtained from a manikin are used to make decisions about the suitability of immersion suits to be worn by humans. With manikins, high average values for insulation can be most easily achieved by ensuring that an immersion suit assembly provides at least as much insulation, and preferably a little more, over the limbs compared to the torso. However, as noted earlier, on immersion in cold water, a human reduces heat loss from the extremities by vasoconstriction and the major pathway for heat loss is via conduction from the torso. As a consequence of the above, suits may gain approval on the basis of thermal manikin tests that are not necessarily of optimal design for human survival, where it is preferable to concentrate insulation over the torso. This problem could be most easily addressed by having different pass criteria for the insulation provided over the torso (higher) compared to the limbs (lower) (Tipton and Balmi, 1996) (Reference 159).

In response to the perceived problems associated with the use of manikins, some organisations (e.g. CEN, ISO) have recommended cold water tests with humans. Instead of measuring insulation, deep body temperature is measured and in order to pass in its category a suit must prevent a given fall in deep body temperature in a given time. Whilst this approach is attractive because it involves the direct measurement of the impact of a suit on the important variable of deep body temperature, it also has some disadvantages. These include:

(a) It is often difficult to get human subjects to sit in 2°C water for six hours. So, the subject pool to which statistics are applied can be small. This is one of the reasons why all the experiments so far have been conducted on small numbers of subjects.
(b) Human subjects do not all behave in the same ways in cold water, i.e. some cool off quicker than others. So, selection of the "right" slow coolers may pass a suit, whereas selection of rapid coolers will fail a suit.
(c) It is important not to choose cold acclimatized subjects.
(d) It is very expensive to use humans because of the requirements for medical ethics approval, physician services at the pool etc.
(e) For evaluation of suits that may fail the test, there is a likelihood of inducing non-freezing cold injury in the human subjects, so ethically and morally, human ethics committees are becoming increasingly unwilling to approve such experiments for pure suit testing to the standard. Alternatively, low peripheral temperature will result in subjects being removed from the water for medical/ethical reasons before a test has been completed.
(f) The flotation angle for testing is inconsistent. The suit manufacturer can add a high Newton lifejacket (which may not been worn with the suit) to obtain better freeboard and hence less chance of neck seal leakage and less hydrostatic squeeze on the back of the suit. This results in better overall insulation.
(g) The suits can only be tested in calm, stirred water or in a pool with a wave maker. Testing in

the open ocean in a sea state greater than Beaufort 3 is not only cost prohibitive, but unlikely to be approved by an ethics committee.

It is concluded that no completely valid way exists of predicting the way a suit will perform in a real sea, during a real accident. However, several ways exist of comparing the performance of different suits in a standard environment. Of these, manikin tests are the easiest and most reproducible. The danger lies in the application of manikin test data to the real world; this danger is reduced as test specifications are more accurately defined (Sowood et al, 1994) (Reference 137).

Summary of Chapter 3

This chapter discusses the key physical issues of design and testing of immersion suits.

- Leakage of as little as half a litre of water into the suit reduces the insulation (immersed Clo value) by 30%. This is why a dry suit is required to protect from the long term effect of hypothermia.
- The insulation value of material on a flat surface is directly related to its thickness. Practically speaking, this means that one can achieve about 4 Clo of insulation per inch of clothing thickness. Increasing the thickness beyond this severely limits a human's physical function. However, the insulative value of material on a cylinder, i.e. the fingers and toes does not increase linearly with added thickness; no significant improvement in insulative value occurs when over one inch in thickness is added. This is why it is so difficult to protect the hands and feet.
- The human produces (even at rest), approximately 500-850mls of insensible sweat every 24 hours. Therefore, if a waterproof suit is to be worn, there has to be some method of removing this sweat from the skin surface. It is this skin wettedness that causes complaints that the suit is hot and unbearable.
- Early measurement of Clo value was conducted in stirred pool water. More recent work has shown that in open water the insulative value is reduced by 15% compared to pool water.
- The overall buoyancy of a very large percentage of immersion suits negates the self-righting ability of approved lifejackets.
- Care must be taken in the design of helicopter passenger immersion suits to ensure the inherent buoyancy does not preclude the ability to make an underwater escape from a rapidly sinking inverted helicopter.
- The pros and cons of using manikins and humans to measure insulation of a suit and for passing or failing a suit to a specific standard are discussed.

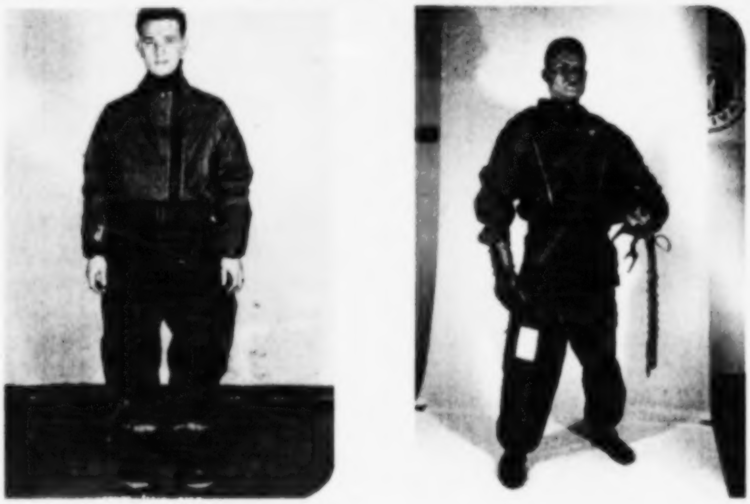
KEY ISSUES IN THE CONSTRUCTION OF THE IMMERSION SUIT

Chapter 4

What is the State of our Immersion Suit Technology in 2002?

In 1986, Brooks (Reference 28) was depressed by the poor quality of suits provided to him for testing. Brand new ones straight from the manufacturers leaked, zippers seized up, ties on suits and gloves tore on initial donning and little attention had been made to sizing and fit. Furthermore, the lifejacket / survival suit interface was very poor. He therefore reviewed the whole topic and concluded that no suit in existence fulfilled all the criteria for an immersion suit and that in its present form had reached the peak of its development. All credit should be given to the pioneers since 1939 who had managed an uphill struggle against much adversity and resistance to produce a reasonably good immersion suit if manufactured correctly. However bluntly put, the one-piece immersion suit developed for the RCAF in 1945 could do nearly as good if not better job than the suits built in the 1980s (Figures 15 and 16). As stated above, the introduction of cotton ventile fabric later superseded by Gortex and introduction of the reliable waterproof zip in the 1980s, had made only marginal improvement in overall performance. He had hoped that the paper would stimulate government, industry and academia into looking at new concepts. This next section addresses the key issues in the design and construction of a good or a poor immersion suit.

Figures 15 and 16: **RCAF Ferry Pilot suit, developed in 1945 (left), and the Canadian Forces CF18 pilots immersion suit developed in 1990 made from Nomex Gortex (right).**



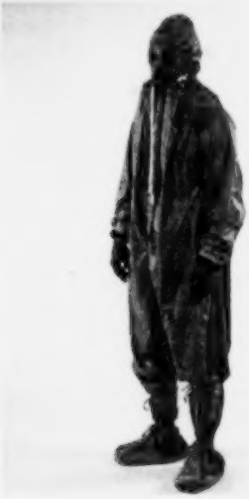
Water Integrity

If the suit is to be designed to protect from the four stages of the immersion incident, then until some creative idea is conceived, it must be waterproof. This brings up the problem of how to close the suit and how to seal it off at the hands and feet.

(a) The neck seal for quick don suits

The draw string method is very simple to manufacture and operate even with cold hands, but it leaks to some degree (Figure 17). This is made worse if the wearer has a poor freeboard. It will also leak on initial water entry. This can be ameliorated to a high degree if the drawstring is enclosed in a very soft rubber sleeve bonded to the collar of the suit. However, it is very good in its application for suits developed for mass abandonment; in this case protection from cold shock and swimming failure are the paramount threat and there will be a lifeboat or liferaft immediately available. It is very useful for suits donned quickly over existing clothing during abandonment. Whatever suit it is applied to must be used with a lifejacket. This system was well proven in the Falklands War.

Figure 17: **Quick-don, once-only suit, note draw string to seal the neck. The advantage is that it is simple, cheap, and can be made for one-size-fits-all type suits.**



(b) The neck seals for constant wear suits

This is achieved by bonding a wide rubber band around the neck. In order to make it a more comfortable suit, the rubber neck seal has been split in the center by a zip. Thus, in theory the neck can be left open for normal work and closed only prior to water immersion. However, this can tend to produce an uncomfortable lump under the chin as in Figure 18. Inserting a comfort flap is a good solution (Figure 19) but the flap must be well designed to avoid becoming snagged by the zip during rapid closure. An alternative to the central neck seal is an offset neck seal. This zip which closes at the side of the neck works reasonably well if the zip can be secured firmly in time (Figure 20).

Figure 18: **An example of a central split neck seal. The end of the zip tends to fit uncomfortably on the larynx.**

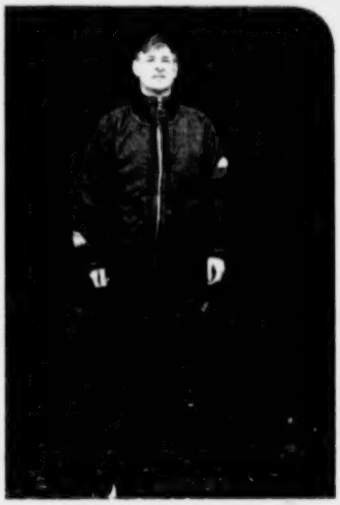


Figure 19: **An example of a central split neck seal where an additional flap has been added for comfort.**

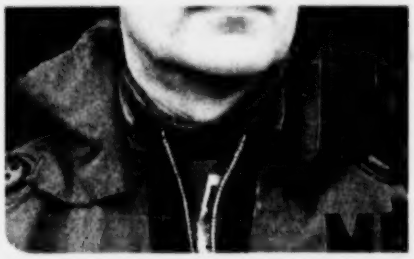
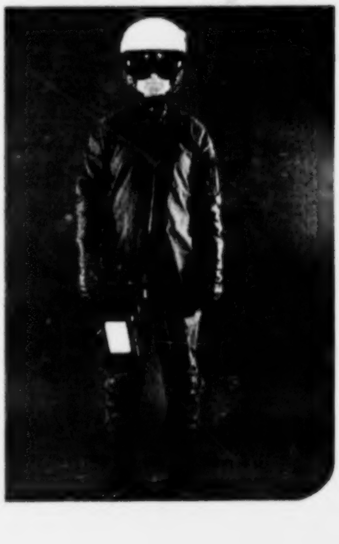


Figure 20: **An example of an offset split neck seal.**



A modification to this idea is to extend the zip into the front (Figure 21) or the side (Figure 22) of the hood. Now the water integrity of the suit depends on the seal of the hood around the margin of the face rather than a seal around the neck. This type of seal must be closed in plenty of time before immersion because of the precision required to adjust the hood on the face, to get all the hair comfortably underneath it, and to ensure the zip is pulled right to the top and secured. It is also not very comfortable to wear this type of suit for any length of time when fully secured for a helicopter if the operators insist on it being secured during flight.

Figure 21: An example of a suit where the suit hood is utilized to protect the neck seal. The zip is positioned in the center and makes for an uncomfortable seal under the mouth and nose.

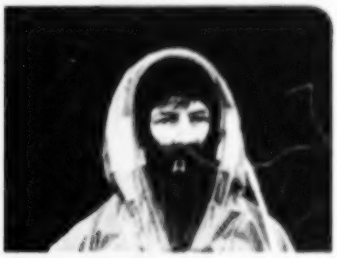
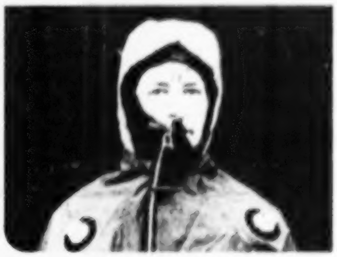


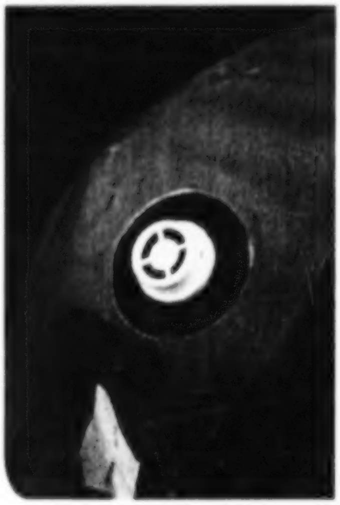
Figure 22: An example of a suit where the suit hood is utilized to protect the neck seal. The zip is positioned at the side to give better clearance for the nose and mouth and less discomfort when secured.



The problem with any suits that utilize the hood to protect the neck seal is that when in the water there is a limited field of vision and ability to hear vital orders. If it is undone in the water, or incorrectly secured in the first place, then the whole water integrity of the suit is compromised. It must also be noted that in a downed, flooded inverted helicopter escape the immediate hydrostatic squeeze on the suit during water entry can cause a sudden rush of air into the hood which simply blows it off. High volume, low working pressure relief valves in the shoulders or the hood work well are essential and prevent this. They however add to the cost and complications of the suit (Figures 23 and 24).

Figure 23: Students strapping into a TEMPSC show an example of a relief valve fitted in the hood to prevent the rapid escape of trapped air from blowing the hood of the face.

Figure 24: An example of a relief valve fitted on the crest of the shoulder. In this case, a valve is also fitted on the other shoulder and in some cases, valves are fitted in the feet too.



Various attempts have been made to manufacture a loose neck seal to allow suit ventilation that can be sealed rapidly prior to immersion. Thus far, quick tightening systems (Figure 25) around the neck tend to leak. The reason is simple – the engineers believe the neck to be a simple cylinder, and any form of circlip that tightens around it will provide water integrity. This is not so, the neck is a complex oval shape with a protrusion anteriorily for the larynx. Thus to date, the only simple and reliable method of providing a seal around this shape is by the use of a continuous rubber neck band (Figure 26). The softer and more pliable the rubber, the better the seal and the better user acceptance. The disadvantage is that user acceptance is not good except in groups such as the diving community who use it on a daily basis. Some companies supply the suits with the neck seal tapered with three consecutively wider concentric rings, the user cuts the seal down to the ring which fits him / her best. People generally find it hot and sweaty, irritable against beards or clean shaven faces. Nevertheless, with current technology, this is still the best way to achieve a reliable watertight neck seal.

Figure 25: An example of a ratchet type seal to close the neck.

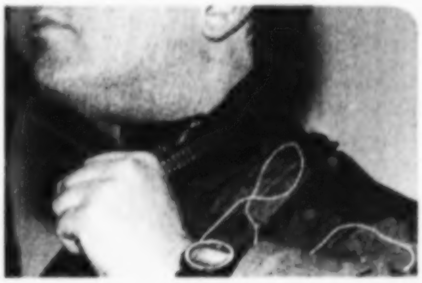
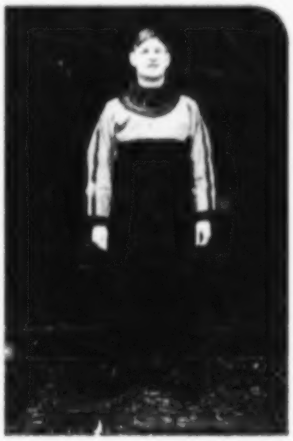


Figure 26: Still the best method of making the neck watertight is the continuous rubber neck band.



(c) Method of entry into and closure of the suit

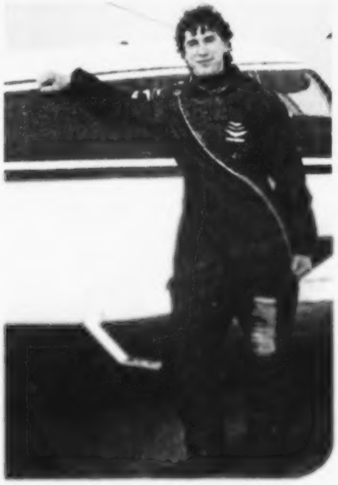
i) Access through the neck

Going hand in hand with the neck seal, must be the design of the suit closure. For very simple quick don suits intended for rapid abandonment with as much clothing as possible, the simple bag type suit with wide entry through the neck is best. The suit is then sealed by the drawstring (Figure 17). The disadvantages to the drawstring are as discussed above: leakage on water entry and water entry when in the water if a poor freeboard has been achieved by using a not very effective life jacket.

ii) Access through the front

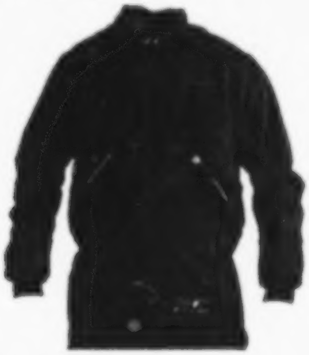
The second method is one of several forms of front entry suit with either a continuous neck seal, split neck seal or hood seal. In each of these a waterproof zip is used. Modern zips, albeit expensive are very good if properly maintained. First, the zip can be run from the crotch in a vertical direction to the center of the split neck seal on the front of the larynx (Figure 18). Unless secured very tightly before immersion, it has the disadvantages of leakage and discomfort when sealed. Second, the zip runs from the crotch to the side of the neck seal (Figure 20). The problems are similar to those of the zip that ends in the front of the neck seal. Third, the zip runs from the crotch to the front or side of the hood (Figures 21 and 22). Problems with the hood seal are discussed above. Fourth, the suit incorporates a continuous rubber neck seal. The wearer must gain access through a frontal opening and pull the upper torso portion of the suit including the neck seal over the head before zipping up securely. A diagonal zip runs from the crotch to the left or right shoulder to secure it (Figure 27). It is better to end the zip at the shoulder and not at the crotch. If the ending is at the crotch and the user does not secure it correctly, then the suit will flood up very quickly. Fifth, the suit again incorporates a continuous neck seal, but the zip starts at the left hip, runs across the back, and then diagonally across the chest up to the right shoulder. Providing the longer zips are well maintained, both these diagonal zip designs make it very easy to put the feet and legs into the suits and pull the neck seals and upper portion of the suit over the head.

Figure 27: Access to the suit can be gained by a diagonal zip. This is a good design for easy donning of the suit.



Sixth, the torso portion of the suit is opened out in half by a W-shaped zip. This starts to one side of the umbilicus, runs diagonally up and backwards around the back of the chest and then returns down the other side diagonally downwards to the other side of the umbilicus (Figure 28). It can be operated single handed. This type of zip provides the greatest aperture for donning the suit. It has the advantage that the suit can be worn for instance in the crew room or bridge of a ship only half donned with the sleeves folded in front across the chest.

Figure 28: W-shaped zip that provides easy access to the suit for donning.



Seventh, entry into the suit is gained by a long, horizontal aperture running across the chest from right to left armpit (Figure 29). The disadvantage of this system is that due to the folds in the suit it is not very easy to make the final seal. Pull tabs have to be incorporated into both wrists to approxminate both edges of the zip, so that the slider can run smoothly across the chest and make the seal. This only adds complications to the suit and increases the cost (Figure 30).

Figure 29: Access to the suit can be gained by a horizontal zip

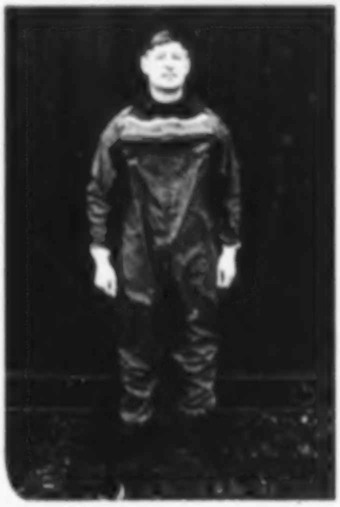
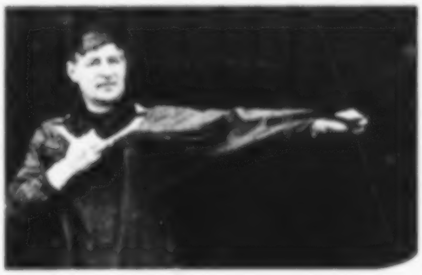


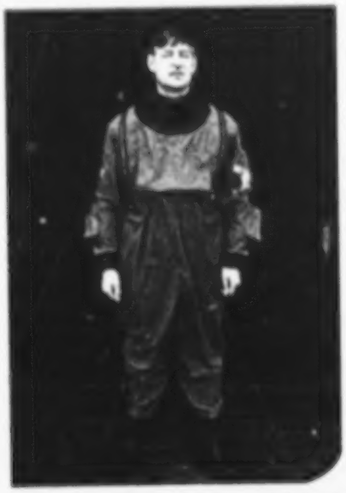
Figure 30: The horizontal zip needs additional ties to straighten out the two side of the zip prior to closure.



iii) Access through the back

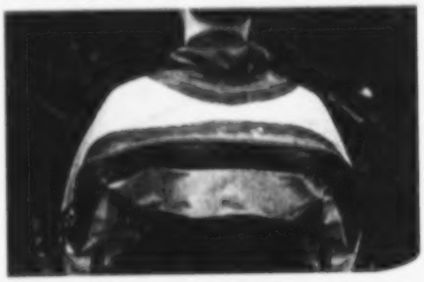
All the back entry suits depend on a continuous rubber neck seal for the neck. The first type of suit is closed by a horseshoe zip (Figure 31). This starts on the front of the left side of the chest, runs around the left shoulder across the tip of the shoulder blades, around the right shoulder and down to the front of the right side of the chest. If sized to the individual correctly, it can be operated single handedly, makes a very comfortable fold in the suit, and it is easy to don the suit. Like the W type of zip suit, it gives very good access for donning and the front half can be folded down. The suit can be worn partially donned with the sleeves tied in the front.

Figure 31: The horseshoe zip. It can be secured single handed and is easy to don.



The second type of suit favoured by commercial divers is closed by a horizontal back zip running from armpit to armpit (Figure 32). This again is a good system, it makes a comfortable fold in the suit, and the suit is easy to don. The disadvantage is that a second person must secure the zip, the suit cannot be donned single handed.

Figure 32: The rear zip, which makes a very comfortable crease on the back, but the drawback is that it cannot be secured single handedly.



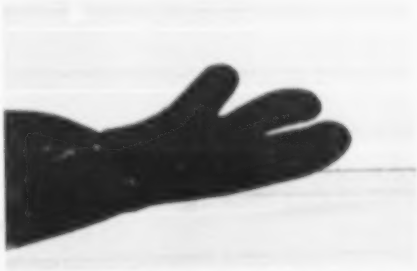
iv) Other methods of closure

Under development by the US Navy is a very long zip that starts on the front of the mid chest, runs through the crotch and up the back of the suit. What advantage this system has over current systems is unclear at present until a production version is trialed.

(d) Closure of the wrists (and decision about integral or separate gloves)

The best guarantee for a water tight seal at the wrist is to incorporate the glove, whether it be a five finger glove or a lobster claw type of glove into the suit (Figure 33).

Figure 33: The standard three finger lobster claw type glove incorporated into the ship abandonment suit.



This, in practice works very well, but any tasks that require fine tactility will not be easy. A second option is to incorporate the glove into the suit and have some form of zip that allows the hands to be free. This works better in theory than practice. If the hands are free as may be the case for helicopter passengers, then on the command ditching the hands must be placed rapidly inside the gloves and the gloves secured by the zip. The first hand gets zipped up correctly, but the second hand due to loss of tactility of the dominant hand, barely gets secured. If there has been any hand injury, the second glove will likely not be secured.

A modification to this idea is to fit a glove to the suit and protect water running up the sleeve by a continuous rubber wrist seal. However, this does not solve the tactility problem. Not only is it still difficult to secure the second glove, but also unless the glove is well designed and reinforced at the apex of the zip, the uneven pull on the zip often rips the neoprene rubber glove.

The general consensus of opinion is to secure the wrist seals with a continuous latex rubber seal and place one glove into a pocket on each sleeve

(Figure 34). It is very important during servicing to powder the seals well with talcum. This prevents the thumb or fingers from puncturing the seals during donning. For more sophisticated suits such as the submarine escape immersion suits, the wearing of a cape leather glove on the suit protected by a conventional rubber wrist seal provides enough insulation to allow function to do critical tasks. Then, for the long term survival an over mitten with foam insulation is provided. Servicing the suits with continuous wrist seals is labour intense. Suits can become unserviceable because the individual pushes his/her finger or thumbnail through the rubber seal. The old seals and glue must be stripped off the suit, the fabric cleaned and the new ones glued on. This all takes time and money, and occasionally will prevent people flying offshore until a serviceable suit is obtained. A concept in use by the diving community is a quick release rubber seal that is held onto the suit by a rubber toroid seal which fits into a circular plastic groove secured around each wrist on the suit. This allows for the seals to be changed in under a minute. This concept warrants investigation by the marine industry (Figure 35).

Figure 34: **Probably the best method is to secure each glove on a pocket on the sleeve and make the wrist watertight with a continuous rubber seal.**

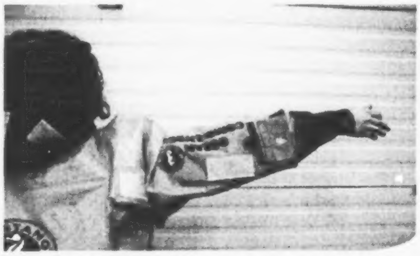
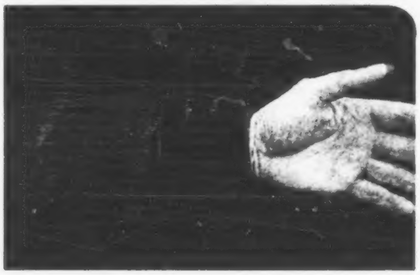


Figure 35: **An example of a quick change rubber wrist seal.**



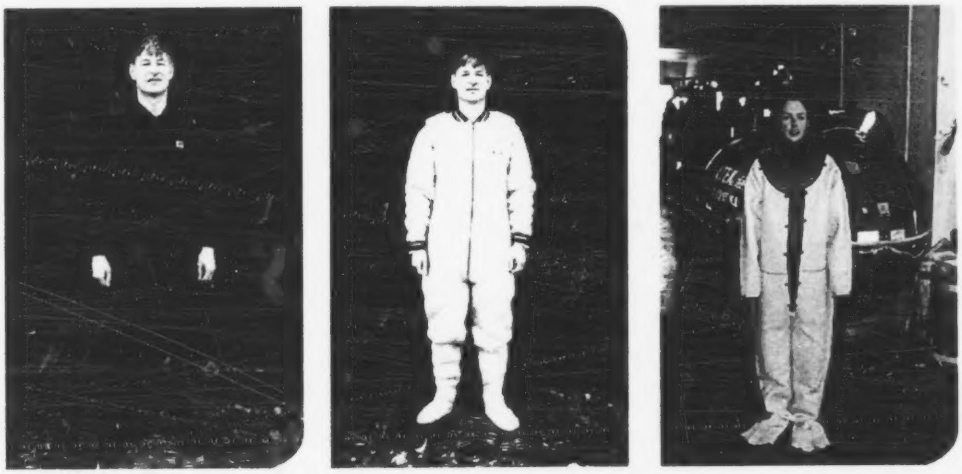
(e) Fabric for the suits (with or without incorporated insulation)

The suit is basically made from an outer shell fabric that provides the water integrity and an inner liner which provides the insulation or Clo value. The two can be combined (insulated suit) or separate (uninsulated suit).

The outer shells of the original suits were made from neoprene or chloroprene coated rubber. These are impervious to sweat. When cotton ventile fabric was invented, everyone thought the problem had been solved. This was not to be the case. As previously stated, the fabric is expensive to manufacture and expensive to mass produce a suit. Furthermore, oils and grease degraded its water integrity and to achieve the water integrity it must be made of two layers of materials. The invention of Gortex and then fire-retardant Nomex Gortex fabric has certainly improved the water integrity of the suits once the system of hot taping the seals was perfected.

For those manufacturers who choose to produce insulated suits in two parts, then the options for the liners are very good. There are a number of synthetic pile liners available that can provide different Clo values for different cold water conditions (Figures 36, 37 and 38). They are all hard wearing and launder well. In addition, the new liner can be had with a wicking layer that transfers the water vapour from the skin to the surface of the suit, however, the shell fabric must be breathable for this to work. There are also other thin, flexible foam liners (Figure 38) available that can be used as well. The advantage of producing a suit with a separate liner is first that it is much easier to launder, second, the wearer can add or subtract thickness of liner to match the environmental conditions and third the suits wear well and are not as expensive to maintain.

Figures 36, 37 and 38: **Three examples of liners. The one on the left and one in the center are of synthetic fibre of medium (left) and greater thickness (center). The one on the right is made of one of the modern synthetic foams.**



The insulation of the suit can be provided by an inflatable liner. The advantage to this is that the suit can be worn as an uninsulated suit for normal purposes (i.e. with the equivalent Clo value of a business suit), and the insulation is only added when the person is in a survival situation. This is a very good idea and is the direction that research should pursue. The Royal Navy marketed the first operational inflatable immersion suit using CO2 for their submarine escape suit in the 1950s/1960s. The principle is used in their current Mk10 submarine escape suit. I.L.C. Dover (Delaware) produced an experimental CO2 inflatable aircrew flying coverall for DCIEM in the mid 1970s that worked well, but it was very labour intense to maintain its gas tightness and it was a very expensive suit to manufacture. Nevertheless, it proved the concept was good (Figure 39). In the 1980s, Shell, the Shark Group and the University of Surrey invented an advanced, inflatable helicopter passenger immersion suit including an integrated lifejacket (Figure 40). This was made from urethane coated nylon. This made it much cheaper to manufacture than the original ILC Dover model. It is R.F. sealed to compartmentalize the CO2 gas. Thus, a leak in one section will not compromise another section. A further advantage is that it keeps the insulative thickness over the back and pressure areas, preventing gas from migrating to the front. This suit is now in service and represents the latest technology in immersion suits with an integrated lifejacket.

Figure 39: **The experimental C02 inflated ILC Dover pilots immersion suit. One boot has been removed to show the inflatable liner.**

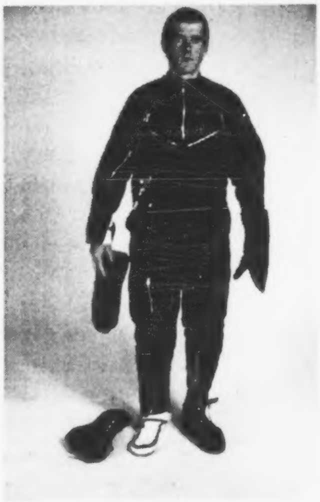
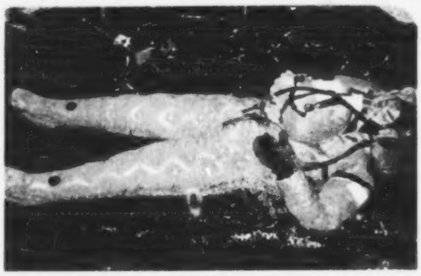


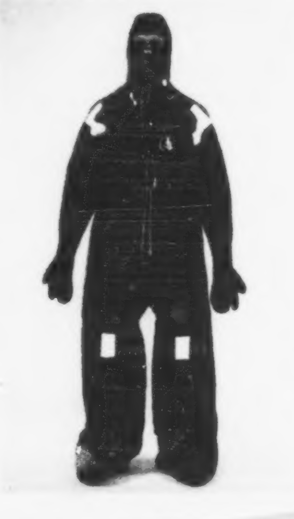
Figure 40: **The Shell, Shark Group, University of Surrey RF heat sealed inflatable survival suit worn with an asymmetric lifejacket to ensure self-righting.**



Other manufacturers choose to bond the outer shell fabric with the inner insulated liner. The disadvantage to this is that it is not possible to change the insulation according to operational conditions. The shell fabric is usually made from a durable nylon mixture of fabric attached to a three or five millimetre foam rubber (Figure 41).

There are now PVC or urethane coated fabrics that provide good protection from oils and greases; there are good high tensile nylon fabrics that resist ripping and tearing; and there are bondable elasticated fabrics that can be mated to any of the foams such as Ensolite to provide stretch to improve the workability of the clothing. There is also Gortex that can be bonded on a number of different fabrics. Therefore, for the first time, those who work on or over the water for a living can choose the fabric best suited to their specific operation.

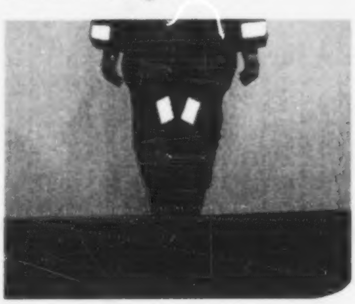
Figure 41: **Ship abandonment suit that relies on a durable nylon cordura mixture of fabric bonded to neoprene foam rubber.**



(f) Closure at the feet

Several ideas have been used to close the suit at the feet. One of the better ideas is to provide a pair of Wellington type boots bonded on to the legs. These are very good for walking around the deck, going up and down ladders and scrabbling nets, but have the disadvantage that they have to be sized to the individual. When in the water they are very buoyant, bringing the survivor's legs up to the horizontal position. People of short stature have difficulty getting themselves horizontal in the water to do essential survival routines or positioning themselves to climb into a liferaft (Figures 14 and 42).

Figure 42: **A helicopter suit with rubber Wellington boots bonded to the legs.**



An alternative is to make a sockette out of the immersion suit fabric with a lightly reinforced sole (Figure 43). Thin sockettes can then fit inside the person's footwear. Other sockettes have a reinforced sole and do not need an additional boot. In some cases, as in the ship abandonment immersion suit, the sockette can be made expandable and the footwear can be worn inside the sockette. These sockettes generally work reasonably well. The footwear fitting inside the sockette tends to make for a clumsy gait and extra caution is needed for climbing ladders and walking along companionways. Because of the wear and tear experienced in training schools, they require additional reinforcement for training suits.

Figure 43: **A typical military immersion suit with sockettes bonded to the legs.**

Summary of Chapter 4

This chapter discusses the key issues in constructing an immersion suit. Specifically:

- The difficulty of achieving a good neck seal. The only proven, reliable way is to use a continuous rubber collar around the neck. Split neck seals tend to leak.
- Wrist seals are also best designed using a continuous rubber collar, but suits can be very quickly made unserviceable if the seals are not well powdered and the occupant punctures the seal with a finger or thumb.
- Entry into the suit can be made from the front or the back. There are pros and cons to both methods, but whichever method is used, it must be possible to don the suit single-handedly and the zip closure must be of good quality, otherwise the suit will leak badly.
- Gloves are better provided for as a separate item stowed on the sleeve rather than incorporating them into the suit itself.
- Rubber Wellington type boots integrated into the suit are the best option for footwear, but must be sized. Necessity and cost may require the substitution of expandable sockettes.
- There are now a large variety of outer shell fabrics for the suit and inner thermal liners. Having a separate inner liner makes it easier to launder and maintain the suit and match the required insulation with the thermal environment.
- Overall, the quick don, once-only suit with drawstring around the neck provides a cheap, practical compromise that was well proven during the Falklands War. It is very useful for donning quickly over existing clothing prior to abandonment.

Chapter 5

INTER-RELATIONSHIP BETWEEN THE IMMERSION SUIT AND THE LIFEJACKET

It is not possible to discuss survival in cold water and the immersion suit without considering the part played by the lifejacket. For extensive information on the design and development of the lifejacket, the reader is directed to the specific text book by this author (Reference 29). The principle of pneumatic lifejackets has been around for longer than people realize. Inflatable animal skins were used by Asur Nasir Pal's army as early as BC 870 to cross a moat; but subsequently only crude lifejackets were available to the sailor until the mid 19th Century. As stated in Chapter 1, the principal reason for this was that sailors' lives were considered cheap and drowning an occupational hazard and due to fate. At the Battle of Trafalgar in 1805, sailors clung to flotsam and jetsam for up to 15 hours before rescue. Impressment and wrecking did not encourage the development of lifejackets. However, the advent of iron ships around 1850 meant that ships sank more quickly; there were fewer spas and masts to cling to, and deaths at sea increased dramatically. Finally, there was some incentive to develop a lifejacket for the shipwrecked sailor.

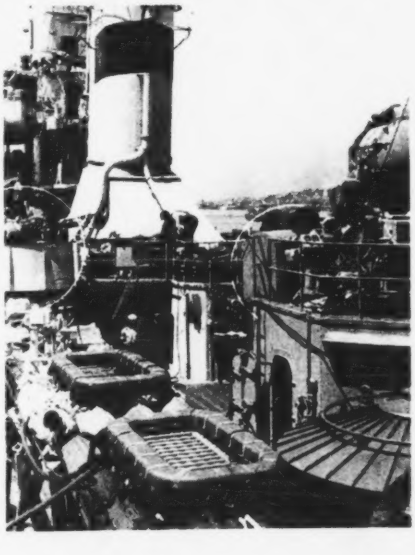
In 1851, again as mentioned in Chapter 1, Captain John Ross Ward carried out the first human factors evaluations on a series of eight different lifejackets for the Royal National Lifeboat Institution. They chose his own design of cork lifejackets providing 25 lbs of buoyancy; this style of lifejacket was in service with the Royal Navy until the 1930s and was still used by many volunteer lifeboat crew until the end the World War II (Figure 8). The first legal requirement to carry lifejackets on passenger carrying vessels was introduced by the US in 1852, followed by France (1884), Britain (1888) Germany (1891) and Denmark (1893). Buoyancy was provided by cork, wood shavings, balsa or rushes. Kapok was not introduced until about 1900. Macintosh had invented the technique for rubberizing fabric in the early 1820s, there were still no reliable inflatable lifejackets in service before the 20th Century.

It took a calamity the size of the RMS Titanic to force the world to produce an international lifejacket standard. This occurred in 1912 at the first IMO SOLAS convention. The standard required a buoyancy of 15 1/2 lbs, but did not specify any oronasal clearance. As already noted, no one considered investigating the physiology of drowning in cold water and applying any scientific logic to lifejacket design.

Subsequently, at many of the marine inquiries following an accident, witnesses reported that the drowned victims were generally found face down in the water wearing lifejackets. The sinking of the Vestris in 1928 was a typical example of this where 112 lives were lost. This was cause enough to reconvene the second SOLAS committee in 1929, yet the lifejacket standard was not improved.

As has been stated several times already, the Navies of the world believed in the philosophy that flotation should be provided for the castaway in the water rather than on or out of it. That led to the development of a whole series of floats and rafts (Figure 44). Very few men were supported out of the water, the majority were required to hang on to becketted lines around the rafts up to their necks in frigid water. Believe it or not, when the Royal Navy went to war in 1939, the sailors were not issued with any personal flotation devices. It was only the personal intervention of Admiral Woodhouse that caused the Admiralty to re-issue an outdated Admiralty pattern No. 14124 inflatable rubber belt which provided 9 1/2 lbs of buoyancy. This had already been rejected half way through the First World War as unsatisfactory! Yet this was to be used by the RN throughout the war and for some of the war by the Canadian and New Zealand Navies.

Figure 44: The Carley Float



During the Battle of Britain, the Air Sea Rescue Service noted many drowned airmen face down in the North Sea; yet they were wearing their supposedly superior inflatable Mae West – why was this happening? This precipitated the pioneering work by MacIntosh and Pask to examine the behaviour of an unconscious human in the water (Reference 107). Wearing different lifejackets, Pask was anaesthetized many times and placed in the pool at Farnborough to evaluate flotation angle, free board and ability to self-right. Their findings laid the foundation for the modern lifejacket. In Germany following the sinking of the Bismarck investigators noted that the sailors were found face down, drowned wearing lifejackets. They instigated an extensive research program and to this day demand substantial head support to keep the oronasal cavity clear of the water.

Post war, all of these losses and equipment failures were reported in the Talbot Report (Reference 147) and McCance's et al study for the Medical Research Council (Reference 108). This has already been explained in Chapter 1. However, what is not known is that a parallel R&D project was started to replace the RN inflatable life belt. This was led by Lt. Cdr. George Nicholl, who flew during the war in the Fleet Air Arm and was the technical advisor to the Royal Naval Life Saving Committee. He was ably assisted by E.C.B. Lee, who had been a naval officer and had seen war service too. Between them, they recorded many testimonies from witnesses who had observed humans drown and humans who had been saved from drowning. This work was produced in a series of reports which sadly appear to have been lost, but fortunately Nicholl did publish the majority of his findings in the first survival-at-sea book in 1960 to coincide with the 1960 SOLAS convention (Reference 123).

Lee continued with his work to improve lifejackets and produced a paper in Rome in 1965 on the observed performance of humans who had drowned or near drowned during the Second World War. This section of his paper is quoted in full because the findings are based on thousands of real events in the open ocean and cannot be replicated by academic investigators (Reference 97).

Buoyancy

Experiments by Borelli and Altier, reported by Paoli Moccia in 1794, showed that most men have a density less than unity. Mackintosh and Pask showed that an unconscious man, breathing lightly, sinks in fresh water. Tests on Service personnel in Great Britain indicate that about 10% are negatively buoyant in fresh water and about 2% in salt water. A clothed man, carrying military equipment, unassisted by a lifejacket, can keep afloat for 5 minutes by his own efforts. Tests in the USA show that the following pulls are required to sink adult persons:

male	6 lbs. (2.7 kg)
female	8 lbs. (3.6 kg)

The buoyancy of the naked man depends on physique, lung capacity and the extent to which the lungs are filled with air. In general, for immersion in calm sea water without making any swimming movement: A man of average build will float upright with his mouth and nostrils just clear of the water when his lungs contain the amount of air breathed in at a normal inspiration. A man of specifically heavy build, e.g. a fat man, will float with his mouth and nostrils clear of the water even when he has emptied his lungs by a deep expiration. A man of specifically light build, e.g. a thin man, will just remain afloat with his mouth and nostrils clear of the water if he inflates his lungs as far as he can by taking a deep breath. Designing for the worst case, the specifically heavy man, a buoyancy aid equivalent to the vital capacity of the lungs, about 4.5 litres, is required to keep the mouth and nostrils out of water. A further 1.7 litres is required to bring the rest of the head and neck out of water in order to provide a safety margin, thus making a total of 6.2 litres. For the survivor at sea additional buoyancy is required to take account of the following:

weight of waterlogged clothing and footwear

possible weight of water in the lungs (a drowned man weighs 9 lbs. (4 kg) in water)

some of the lifejacket is usually above the water and does not contribute to buoyancy

Posture

The body extremities are denser than the trunk and the spine allows bending forwards much more easily than backwards. An unconscious man in still water therefore tends to float with his face downwards, his head slightly flexed with the chin on the chest (a natural defence in man's normal environment, facilitating breathing); the heavy arms and legs are free to flex at the shoulders and hips and in consequence hang vertically; heavy footwear, such as sea boots, emphasize the effect and urine in the bladder and the heavy pelvic structure also tend to put the legs down; air in the lungs, stomach and upper part of the intestines provides buoyancy and the body therefore floats with the upper/middle part of the trunk uppermost. The unconscious, unaided by a lifejacket, who floats face downwards, will drown. The posture of the unconscious female depends on body-build. Some women have the flotation characteristics as men; others, with large breasts and thick layers of fat on the belly wall and thighs, may float face upwards and a water logged skirt hanging downwards will tend to stabilize them in this position. Any buoyancy aid attached to the body will affect posture and should be of sufficient amount and suitably positioned to ensure that the mouth and nostrils clear the water. A vertical posture offers less resistance to vertical oscillations and places the survivor at greatest risk from periodic immersion of his mouth and nostrils. The risk of injury from underwater explosions is also greatest. A supine horizontal position places the body at minimum risk from underwater explosion but at maximum risk of death from choking. A deeply unconscious man floating on his back might die from suffocation due to his tongue falling back. A prone horizontal positions obviates death from choking but the large amount of buoyancy required to keep the mouth and nostrils sufficiently clear of the water would render the lifejacket too bulky for wear. A posture intermediate between the vertical and supine horizontal position is indicated.

Stability

The buoyancy of the lifejacket should be so distributed as to render the man unstable in the prone position and stable in the supine position. That is, treating the man and his lifejacket as a single floating body, the metacentre should be below the center of gravity when in the prone position and above the center of gravity when in the supine position. The center of gravity of a man of average stature is at a position slightly more than 50% of his height above the soles of his feet (standing) and is constant regardless of age. The center of gravity tends to be lower with shorter statures and higher with longer statures. Maximum turning moment to put an immersed man on his back and keep him in this position is obtained by making the distance between the center of buoyancy of lifejacket and the center of gravity of the man as great as possible. This is achieved by so shaping the lifejacket and securing it to the body that its center of buoyancy is as far as possible in front of the chest and as high as possible. Buoyancy is required to support the back of the neck and to prevent the head from drooping to such an extent as to put the breathing orifices under water. This buoyancy reduces the righting moment of the lifejacket and should therefore be of the minimum dimensions to support the head. The buoyancy necessary for automatically righting an unconscious survivor from the prone position is more than that required for safe flotation in the supine position. The part remaining in the water in the supine position should therefore be adequate for flotation and stability.

Effect of waves

Waves impart a vertical motion to man in the water and under some circumstances the motion may become out of phase with the wave motion with the possibility of the man sinking below the wave profile. The lifejacket should have sufficient reserve of buoyancy and the posture of the survivor should be such as to resist the vertical motion relative to the water surface. The emerged part of the lifejacket should be so shaped as to provide a breakwater to keep spray clear of the face. Survivors prefer to face the oncoming wave, they can then prepare for it and time their breathing to produce maximum personal buoyancy. With the back to the wave there is the possibility of the wave breaking over the head and wetting the face. A well-designed lifejacket will keep the survivor in a position facing the oncoming waves. Wind will also stabilize the survivor in the position where he faces the wind – wind and waves are usually in the same direction.

Effect of broken water

The air in broken water, surf and foam does not contribute to buoyancy; the survivor will therefore sink lower in the water.

Effect of jumping

It is sometimes necessary to jump into the water from a considerable height when abandoning ship. The lifejacket should therefore impart no injury to the wearer, neither should it itself be damaged, on impact with the water. It is usual to jump feet first, with the legs close together and slightly flexed at the knee, mouth closed, one arm across the lifejacket holding it close to the body and the thumb and forefinger of the other hand closing the nostrils after taking a deep breath and before impact with the water. This obviates danger to the head when striking debris in the water, in injury from the lifejacket and shock from cold water forced up the nostrils.

Progress in the Last 40 Years with Regulations and Standardization

Once Pask was allowed to declassify his data (Reference 107), he was able to work on the improvement of the lifejacket standards. This resulted in the self-righting requirement in the 1960 IMO SOLAS standard. This was followed in 1963 by the British Standard Institution BS3595 standard. For the first time this allowed approval for an inflatable lifejacket. The original requirement was for 30 lbs of buoyancy, this was subsequently increased to 35 lbs. Then in 1973, the US Coast Guard introduced their Personal Flotation Devices regulations for Type 1 through 5 lifejackets and subsequently the Underwriters Laboratories UL standards Type 1123, 1191 and 1517. The first standard that specified 120 mm of freeboard was introduced by the IMO at the 1983 SOLAS convention. After this, a whole series of standards were introduced by Germany (DIN 7928 and DIN 7929), Canada (CGSB 65-7-M88 and 65-GP-14), UK Civil Aviation Authority, US Federal Aviation Administration (TSO-C-13) and finally the CEN (50N, 70N, 75N, 100N, 150N, 275N standard in 1994).

What has Been the Effect of These Standards?

Providing the introduction of the standards has gone hand in hand with a good education program, the effect on improvement in drowning statistics has been quite significant worldwide in wealthy countries. In Canada, the Red Cross report published in 2000 (Barss, 2002) (Reference 17) showed that between 1991 – 1995, the death rate from drowning was steady at 1.8 deaths per 100,000 Canadians. Between 1996-2000, the rate decreased steadily to 1.2, an improvement of 33%. This represents a saving of over 100 lives each year. However, there was no improvement seen for foreign tourists with 129 victims of water related deaths in 1991 – 1995 and the same number between 1996 and 2000. This may be attributable to the lack of an education program for these people. Boating was the leading cause of drowning and males were at the greatest risk. During 1991-1995 only 12% of recreational boaters who drowned wore a PFD and between 1996 – 2000 the figure was 11%!

The World Health Database also shows this trend in drowning statistics, except in low and middle income countries. The overall drowning rate was 7.4 per 100,000 population which equates to the loss of 449,000 people drowned each year and 1.3 million people were injured as a result of near drowning. Males are at the highest risk followed by children under five years old. But in Africa the current rate is 13.1 per 100,000 population (Peden, 2002) (Reference 130). This pattern is common throughout the world. In the Netherlands (Reference 169), over the 20 year period 1980 – 2000, there was a total of 8100 drowning deaths, but the death rate decreased from 3.5 per 100,000 population in 1980 to 1.9 in 2000, and as observed in the Canadian statistics, the majority are male. In 1971, the US drowning fatalities were 20 per 100,000 registered boats. As a result of the introduction of the PFD regulations and good education programs, by 1990 the rate had been reduced to 2.9 per 100,000 registered boats. Brazil has also noted a significant decrease in drowning statistics as a result of an intense education program. There were 7210 deaths from drowning (5.2/100,000 population) in 1979 and this had been reduced in 1998 by 18% (Szpilman et al., 2002) (Reference 146).

But this must not lead to complacency, for instance, drowning is the fourth most common "accidental" cause of death in Australia and the sixth most common in New South Wales. Just over 300 people drown each year on average in Australia; a third of these occur in New South Wales. Since 1992, their statistics have fluctuated with a low point in 1996 with a drowning rate of 1.3 per 100,000 population. Currently the rate is 1.8 per 100,000 population. National figures for 1999 – 2000 reveal a significant increase in lake, river and dam drownings. The hypothesis is that the flat, still appearance of the water gives a false impression of security and yet these conditions are the most dangerous when it comes to drowning (Reference124).

What is the Current Situation?

The evidence shown above suggests that several factors have improved drowning statistics over the last 10 years. These include the combination of understanding the physiology of cold water immersion and drowning; the improvement in the design of a variety of flotation devices; extensive national and international regulations backed up by widely published education programs on drowning prevention and the option of a lifejacket or PFD for everyone whether s/he be a professional sailor, a river pilot, a recreational boater, an aircrew member flying a helicopter over water or a child using a kayak.

We have achieved more in the last fifty years than has been achieved since humans took to water in Biblical times. The recent Congress on Drowning held in June 2002 discussed the progress made in lifejacket development and the direction that should be taken in the 21st Century. At the meeting were experts from North America, Europe, South America, Japan, China, Australia and New Zealand. The following paragraphs are written specifically to address what the expert meeting recommended.

Results of the Expert Meeting on Lifejacket Technology (Amsterdam, June 2002)

(a) Nomenclature – lifejacket or PFD?

What should the flotation device be called? There was a heated debate about this topic. Generally, the device may be called a lifejacket, a lifepreserver, a personal flotation device (PFD) a flotation aid or a buoyancy aid. The problem is that each definition means a different performance specification to different people. Generally speaking, the majority of the public believe a lifejacket or lifepreserver is for protection in offshore open ocean conditions with all the features of high buoyancy and self righting properties. Where there is confusion in the definition is in the terms Personal Flotation Device, Flotation Aid and Buoyancy Aid. The majority of attendees believed that these terms related to a lower performing device than the lifejacket or lifepreserver (less buoyancy and no self-righting properties). These are thought to be for use in inshore conditions and generally for recreational sports rather than for professional use (river pilots, aircrew, etc.). This is where there is a paradox because the Type 1 PFD approved by the US is for offshore operations. Thus if the nomenclature is not defined specifically, it is possible to mislead the public into purchasing a device which is inadequate for the profession or sport in which it is to be worn.

Originally, this author was of the opinion that all devices should be called lifejackets and the difference between each type should be identified by the label which identified the buoyancy and the ability to self right or not. After all, the requirement is exactly the same, no matter what the condition, occupation or sport – to keep the oronasal cavity out of water and prevent drowning. However, after chairing the lifejacket expert meeting in Amsterdam, it is clear that in the world opinion, two specific groups of flotation devices are delineated and this is the approach that Canada should take. First, there are those professionals who work in open water that require a high buoyancy device with self righting capabilities (more on this later) and this should be called a lifejacket. The second group are basically the recreational sporting community. They may need equally as much performance out of the device, i.e. the offshore yachtsperson, but generally the performance of their lifejacket is dictated by the sport that is being undertaken, i.e. passengers on a pontoon boat, individuals sail boarding or kayaking. It is assumed that these people will be conscious when they fall into the water and therefore the need for self righting is not as essential and a reduction in total buoyancy can be accepted. This device should be called a PFD, not a buoyancy aid or a flotation aid. From the discussion, it became apparent there is an additional professional subgroup of people requiring this type of PFD who normally carry out their lifesaving duties on land. Therefore, it must be possible to integrate it with their equipment. These are the police, the firefighters and rescuers involved in flood rescue. So, in the standardization process, there must be the possibility for these professionals to procure a device that can be used with all their other equipment.

If there is to be a subdivision of flotation devices into 2 types (lifejackets and PFDs), then the standards must interrelate because there is so much commonality and neither is completely exclusive. The revised standards must be modified to conform with the new ISO / CEN / IMO standards. Furthermore, Canadian representation from both groups at international meetings such as IMO, CEN, and ISO is required.

(b) Mandatory Wearing of Lifejackets

A regulation that requires passengers and operators of small vessels to carry lifejackets in the boat, but not wear them is ineffective, and does not prevent drowning. As has clearly been demonstrated in Chapter 1, as the victim is suddenly immersed in cold water, the cold shock causes a huge inspiratory gasp and s/he starts to hyperventilate while struggling to keep the oronasal cavity out of the water to prevent drowning. At this time, it is quite impossible to don any form of flotation device. As Lee pointed out, a clothed person without any equipment can stay afloat for about 5 minutes and then will drown. It must be worn before water entry. Many European nations now demand that PFDs be worn in all small vessels and enforce these regulations. At present, it is not possible to find the relationship between improvement in drowning statistics and mandatory wearing of a flotation device. A study by the Canadian Life Saving Society is about to commence to examine the feasibility of legislating the wearing of PFDs in small vessels.

(c) Wearer Acceptance and Requirement for a Continuous Updated Education Program

Going hand in hand with the requirement for enforcing the regulations is to listen to the customer and observe the change in sporting fashions. A good example of this is the introduction of the bicycle helmet which the majority of the general population complied with voluntarily before legislation was introduced about three years ago. The reason being that the helmet looks good and appeals to the macho image of the people most at risk, i.e. the 12-30 year old male.

We have only recently got over the hurdle of not requiring a PFD to be international orange or bright yellow, and only slowly are the manufacturers constructing better fitting and better looking PFDs. The committee was unanimous in their opinion that fashion goes hand in hand with positive or negative wearer acceptance. Simply put, a lifejacket will be worn if made out of fashionable colours and styles, but not if it is made from a boring orange or yellow fabric. Starting in kindergarten with a good continuously updated education program on cold shock and swimming failure where the PFD is most urgently needed and phased in legislation, will it be possible to reduce the drowning statistics even more dramatically. It is also most important to accelerate the introduction of more inflatable lifejackets to provide user confidence and reduce the individual cost.

(d) Self Righting

The fundamental problem is that at present, there is no good, reliable national or international standard self-righting test for lifejackets. The current test of swimming on the front in the water for three strokes and then allowing the body to relax is not in itself a bad test. It does test for good sea keeping properties of the immersion suit lifejacket providing the test subject is deliberately rotated when in the water to test out the self-righting properties. Generally speaking however, test subjects cannot truly relax in the water to represent an unconscious person. Even if they have been taught biofeedback techniques to relax, it is difficult to achieve international conformity. The test also does not account for those people who fall off the side of a ship at all different attitudes into the water, and this cannot be simulated. It has been noted on many occasions that lifejackets that have been SOLAS approved will not self-right humans wearing insulated immersion suits (Hermann, 1988) (Reference 76) and (Armstrong et al., 1994) (Reference 11).

The principal reason for this is that there are practical problems here at a standards level. Assume that lifejacket manufacturer A and lifejacket manufacturer B work independently. Suit B is submitted for testing with lifejacket A in a combined test, which they pass. Unknown to B, A makes a small design change that does not affect approval of lifejacket A alone, but now the combination of A and B fails. Who is responsible? How should this be regulated? The answer is a new integrated immersion suit system standard. This would then solve the problem of yet one more layer of clothing (i.e. the lifejacket) that hinders vision, hearing and swimming capability and in many cases, when used with the 275 Newton lifejacket, the lifejacket must be partially deflated in order to climb into a liferaft

There is the requirement to find a good, realistic self-righting test. This can only be achieved using manikin technology. The first effort was made after the Rye Harbour lifeboat disaster in 1928 (Reference 100). Nothing further occurred until the Macintosh and Pask experiments (Reference 107) in World War II. Following these, Pask purchased a crash test manikin from the Sierra Engineering Co. (Sierra Sam) to evaluate flotation angles and self-righting properties. Sierra Sam is still operated very successfully by Hermann at the Institute of Occupational Medicine in Hamburg. The RGIT in Aberdeen, in cooperation with the RAF Institute of Medicine took this concept one stage further and produced an adult manikin called RAMM. His floating position has been validated against that of humans and is currently the only reliable robust manikin that can be tossed over the side into the sea wearing various clothing and lifejacket combinations. RGIT have now developed a toddler and a baby manikin too. The newer SWIM manikin developed jointly by the US Coast Guard and Transport Canada is not, as yet, reliable and certainly not robust. The next step is to take the SWIM and RAMM technology and develop the two together one stage further. Then a standard self-righting test can be developed. An alternative and dual approach that would be advisable is to improve the fidelity of the US Coast Guard reference vest.

During the Amsterdam meeting, a group from IMO / ISO / CEN carried out a practical trial in Rotterdam. The majority of approved lifejackets were shown not to self right a human while wearing an immersion suit. This precipitated a large discussion on the requirement for self-righting or not. It is important to take a step backwards to enquire why the requirement was initially introduced into the 1960 IMO SOLAS regulations. Throughout this report, the reader will have gathered that during the first fifteen years of research post-war on the physiology of cold water immersion, the focus was on drowning from hypothermia. The logic being that as the human became semi- and then unconscious if turned face down by a wave, the lifejacket would self-right the victim. However, in any sea conditions, even wearing the most efficient lifejacket, crotch strap and face shield, it is very debatable whether the unconscious person would survive drowning or not before rescue.

This requirement for self righting has been strengthened by the pundits who suggested it is necessary in case a person is knocked unconscious as s/he inadvertently fell over the side of a vessel. However, although this must happen, being knocked overboard is not a very rare event, but being knocked overboard unconscious is a very rare event indeed. In the majority of the 140,000 open water deaths each year, the people are conscious when suddenly immersed in cold water.

The mechanism for self righting depends on an asymmetric lever action. It can be achieved with very little buoyancy if (a) the fit of the suit is good and the lifejacket is tight so that the human and lifejacket act as one unit, (b) the placement of the buoyancy is accurate, and (c) a crotch strap is worn. However, to achieve this as was clearly demonstrated in Rotterdam where the suits generally did not fit snuggly and where the customer has the option of many different lifejackets and immersion suits not designed, integrated, tested and approved as an integrated unit (see Chapter 6), then the buoyancy in the suit which provides the thermal protection may be counter productive in producing self-righting.

An additional problem in this complex situation is the case of the rapidly sinking inverted helicopter. Here, the crew and passengers wear an approved immersion suit and an approved lifejacket, yet in combination the lifejacket may not self right the victim when on the surface. But, if the victim is not conscious during the ditching, it is most unlikely that s/he would ever escape from the fuselage in the first instance. If one then assumes s/he is conscious when arriving at the surface, then the requirement for self righting is not as important.

Back in 1767, the Royal Society of Art offered a pneumatic lifejacket to the Admiralty for 27 shillings and an inherently buoyant one for 5 shillings (Reference 29). It will be no surprise to the reader that their Lordships chose the cheaper one. History repeats itself and as one ship owner stated quite clearly at the conference, as long as the device has an approved certificate, we will always buy the cheapest one. So, there is a trade off between wearer acceptance, cost and performance. You get what you pay for. The best value for money to save lives is to provide flotation first to get the person to the surface as quickly as possible to counteract the cold shock, then the second priority is to get the oronasal cavity clear of the water to aid the person to await rescue or swim to a safe refuge.

This author does not advocate the elimination of the self righting requirement, but recommends that it is only applied to very specific, sophisticated types of lifejackets, i.e. for fighter pilots lifejackets where on low level high speed ejection, the pilot might find him/herself parachuted violently into the water at an abnormal angle. At a later date as technology advances and becomes cost effective to implement into lifejacket technology, then it may be possible to add the requirement specifically to other devices for offshore lifejackets and ultimately for integrated immersion suit systems.

Removing the self righting requirement and replacing it with a performance standard that requires good lift of the oro-nasal cavity out of water and a statement that the device should produce an unstable condition in the prone position and a stable position in the supine position is a much more practical way to save lives.

(e) Face Shields & Crotch Straps

Anyone who has spent any time in open water with any wave splash and wind understands the huge improvement in performance with the addition of a face shield and crotch strap, yet few manufacturers offer these options and even fewer people connect up the crotch strap if fitted. This is yet another education problem and the next series of programs should demonstrate the benefit of such additions. All who attended the expert meeting were in favour of strongly promoting face shields and crotch straps.

Summary of Chapter 5

This chapter discusses the effects of the rapid progress of development of lifejackets since 1945 and the review of the current technical issues discussed at the conference on drowning in Amsterdam in June 2002.

- By 2000, there were national and international standards in place for lifejackets and personal flotation devices. The effect has been to reduce the overall world drowning statistics to 7.4 per 100,000 population. In the more wealthy countries the improvement has been more impressive. Canada has now a rate of 1.2 per 100,00 population and the Netherlands have a rate of 1.9 per 100,000 population. Common among all countries is the fact that males between 15 and 35 are most at risk and only about 10% of drowning victims were wearing any flotation device.
- There are several issues that need resolution:
  (a) the nomenclature of flotation devices, lifejackets versus PFD, etc.
  (b) the issue of the requirement to self right or not
  (c) the development of a reliable self righting test
  (d) whether the requirement for self righting is necessary when wearing an immersion suit
  (e) the requirement or not to regulate the mandatory wearing of lifejackets on small vessels
  (f) education of the improvement of performance with the use of crotch straps and face shields
  (g) the importance of wearability and how much fashion plays in user compliance
- In the design of any flotation device, the most important criteria are: (a) to return the victim back to the surface as quickly as possible to protect from drowning from cold shock, (b) to provide good oronasal clearance to prevent drowning during the subsequent period follow-

ing the cold shock stage and (c) require it to produce an unstable position in the prone position and a stable position in the supine position to protect from drowning during the development of hypothermia.

- Flotation devices should be categorized as either lifejackets for open water operations and Personal Flotation Devices for recreational and domestic use. Current standards should be modified to recognize these two groups that will share many of the same features and be in line with the new merged ISO and CEN standards.
- If the decision is made to develop new standards for lifejackets (inshore and offshore) and PFDs (generally domestic and recreational) then because there is so much commonality between them, neither must be developed in isolation of each other. Furthermore, it is essential that preferably the committee chairman or senior representative for both standards should both attend each other's meetings and also international meetings with IMO/ISO/CEN. If this does not happen an incongruous situation may occur where common essential parameters may not be in agreement.

Chapter 6

WHO NEEDS PROTECTION AND WHAT REGULATIONS ARE REQUIRED?

Who Needs Protection?

It is important to remember what Golden said in his presentation to the commission of the European Committees in Luxemburg in 1983 on hypothermia, exposure, rescue and treatment. This is quoted in full. It is as true today as when he made the presentation nineteen years ago.

The above considerations emphasize the importance of a careful assessment of the overall nature of the threat before deciding on a solution to the problem. It is apparent that when one is considering the environmental problems associated with the European Offshore Oil and Gas industry one is dealing with a complex multifactoral problem with many interacting facets. Providing a solution to one facet alone is unlikely to solve the overall problem. There is a tendency in recent years to overemphasize the problem of general hypothermia, whereas the acute incapacitating problems of cold are much more likely to lead to death from drowning long before hypothermia may develop. By concentrating one's efforts on providing protective clothing for the individual, in the endeavour to delay the onset of hypothermia following immersion, one is frequently embarking on a pathway which is not only economically expensive, but also involves such a degree of technical sophistication that is in danger of failing to function as designed when donned quickly in an emergency. As the majority of deaths following immersion occur in the early stages before hypothermia develops, preventative efforts should be directed toward providing protection against the short-term incapacitating effects of cold and protection against drowning.

Added to this important statement was the advice given by Tipton in 1993 (Reference 156). In his paper, he recommended that the process of providing protective equipment for an individual should start with the identification of all the hazards. If more than one hazard exists then the different pieces of equipment developed for protection against each of these hazards should be regarded as components of a larger system; these components should complement each other and operate as one integrated survival system to be specified and rated accordingly.

Aside from the military requirement, there are basically eleven categories of occupations which fall into three groups that need protection. Many of these people need similar equipment but with modifications depending on their specific trade. Before proceeding it is important to identify these groups. In order to explain the logic for placing these occupations into three groups, some recent accidents are quoted.

Group I: Constant Wear Suit 0.25 Clo or 0.75 Clo insulation?

Group I

- **Harbour / river pilots**
- **FRC operators**
- **Helicopter pilots and pilots of lightcraft flying over large expanses of cold open water**
- **Helicopter passengers**
- **Professional fishermen and fish farm operators**
- **Professional / offshore yachtsmen**
- **Recreational boaters and skidoo operators**
- **Those working close to or over water without fall arrest (i.e. bridge construction workers);**

First, there are those people who require a constant wear suit that can be worn continuously for an eight hour shift with no problem and minimal discomfort. Probably most at risk are fishermen. A typical accident is quoted below. If rescue is potentially close at hand and the survivors can be rescued within 90 minutes, then a very good light weight 0.25 immersed Clo dry suit can be designed for them.

Fisherman killed when herring seiner capsizes: Six crewmen survive accident. (The Chronicle Herald, 3 October 2000)

A herring seiner's captain died Sunday night when he and six crewmen were tossed into the water after their boat capsized off Yarmouth under the strain of a full load of fish. A seventh crewman watched in horror from a nearby power skiff as the 21-metre Flying Swan out of Wedgeport turned over in a matter of seconds 53 kilometres south of Yarmouth.

The same logic can be applied to the profession of harbour or river pilots as demonstrated in the accident below.

Two crew missing after tugboat sinks. (Globe &Mail, 24 October 2001)

Detroit. Two crew members were missing after a tugboat that delivered mail and pilots to passing Great Lakes freighters rolled over and sank in the Detroit River early yesterday, the US Coast Guard said. Two others, both Canadian freighter pilots, were rescued. The accident occurred as the tug J.W. Westcott II was taking two pilots to the Sidsel Knutsen, a Norwegian tanker carrying gasoline, said Coast Guard Lieutenant-Commander Brian Hall.

The third case of an FRC operation quoted below is a case where the detail is not specific enough to draw conclusions because the time in the water is not stated, nor is the type of suit, i.e. a wet or dry suit. This is a good case to demonstrate that the operators must be given some options on the suit they choose, depending on potential rescue time and water temperature. In this case, the potential for death from cold shock or swimming failure within the first few minutes of immersion was high, therefore the minimum requirement would be a dry 0.25 Clo suit. However, if rescue could not be guaranteed within 90 minutes, a dry 0.75 Clo suit must be substituted.

Two die as U.S. Coast Guard vessel flips. (The Halifax Herald, 25 March 2001)

A U.S. Coast Guard boat patrolling the Niagara River along the U.S. – Canada border capsized and two of the four crewmen died Saturday after floating for hours in the icy waters of Lake Ontario. "A four-foot (1.2 metre) wave hit the bow of the boat, swamping it and flipping it over" said Adam Wine, chief petty officer at the Coast Guard's Buffalo station. The 6.5 metre, rigid-hull inflatable was found floating bow up along the lake shore about 1.5 kilometres east of the mouth of the river, and the crewmen were rescued soon after midnight about five kilometers northeast of the river, Wine said. River conditions had been choppy Friday night, with waves of about half-a-metre and occasional swells as high as one metre. The crew was supposed to report in every half-hour but never did, and a multi-jurisdictional search by air and sea began about two hours after the boat had left port. The rescue was hampered by heavy snow. A fire rescue boat located and rescued the four men, but it was not clear how long the crew had been in the water.

The fourth accident quoted below illustrates that aircrew other than military aircrew flying over large expanses of cold water also need protection. This unprotected pilot disappeared off the Grand Banks of Newfoundland. It is only speculation how death occurred, but is likely from cold shock as the cabin rapidly filled with water. This could have been compounded by injury that precluded jettisoning the door to escape. Therefore, such professions also require a comfortable constant wear suit. The decision to wear the lightweight 0.25 immersed Clo will be made on whether rescue can be guaranteed within 90 minutes, or a liferaft can be boarded, otherwise a 0.75 Clo suit is required.

Sea search on for downed pilot: Florida man ditches after two-seater's engine fails. (The Sunday Herald, 23 September 2001)

Air and sea searches are underway for a Florida man whose small aircraft went down in waters not far from the Hibernia oil platform, some 370 kilometres east of St. John's. The man who was flying a common route for light aircraft from St. John's to the Azores, radioed at about 6:30 a.m. that the only engine of his two-seater Cessna 172 had failed and he was ditching into the ocean. It's believed that he had no liferaft and that he wasn't wearing a survival suit. The seas were about a metre high, the winds light at about 30 kilometres per hour and the water temperature about 13C. Searchers said visibility was good.

The standard that currently applies to Group I requires the immersion suit to have 0.75 immersed Clo of insulation. Because the 0.75 Clo suit can be hot and uncomfortable in air, it can, in some cases be either ignored and not donned, or incorrectly secured. It is important to note that the wearer must

know why and when to wear the suit, how to wear the suit and the dangers of allowing leakage. Otherwise, as demonstrated in the next paragraph, the suit will not protect the person. Investigation into whether the survivors or casualties in the Super Puma Cormorant A accident in 1992 (Reference 2) had their immersion suits correctly donned is covered in vague terms casting some doubt that this was so. The majority appear to have been correctly fitted, with the central zip up to at least three inches from the top. Evidence suggested that a majority also had the hood up when the accident occurred. The suit worn by casualty assigned the code NS2 was the only one which was positively identified as having taken in a significant amount of water. The suit was partially unzipped, but it was not possible to determine if it had been like this at the time of impact. The report continued as follows:

> The sea temperature was 7°C and the wave height was estimated to be 8-11 metres. After hitting the water, the helicopter immediately inverted, floated briefly and then sank. Unfortunately, only 12 of the occupants, 10 passengers and 2 crew, were able to escape and subsequently six of these were recovered from the water dead. The remainder, 5 passengers and 1 crew, survived to be rescued 40-85 minutes after the accident. Some of these survivors reported later that they had been in the water with their immersion suits partially unzipped, although they had not been aware of any leakage occurring inside. Rescuers also described finding bodies with their suit partially undone and full of water. Similarly, the divers who recovered the 5 victims from the wreckage confirmed that they were also wearing their immersion suits partially unzipped.

It would appear that in the quest to protect from hypothermia, we have to some degree overprotected this constant wear Group I occupational workers. For the future, providing the immersion suit is tested as an integrated system with the lifejacket, then immersion suits approved to the new draft ISO/FDIS 15027-3 should be applicable to this group:

Class A: Test subjects exposed for a time of 6 hours to water less than 2°C.
Class B: Test subjects exposed for a time of 4 hours to water less than 2°C.
Class C: Test subjects exposed for a time of 2 hours to water less than 5°C.
Class D: Test subjects exposed for a time of 1 hour to water less than 5°C or test subjects exposed for a time of 2 hours to water less than 15°C.

This gives the operator the choice of system for their environment.

Specifically for the fishermen's outfit, the original UK work was commendable, the fishermen's suit offers the greatest challenge to the designers, it has progressed somewhat with the new PVC and urethane coated fabrics and manufacturers are striving to make the suits to match the industries, i.e. the lobster fisherman requires a different suit from the scallop fisherman. The first step is to write a new standard for them that insists that all parts of the suit are positively buoyant. However, it still has a long way to go. The solution to many of the problems now for all the suits is not dependent on the clothing manufacturers, but on the organic chemists and fabric designers, much more funding is required by them before we can make the next technology leap forward.

Group II: Ship Abandonment Immersion Suits

Listed below are the two occupations that require a ship abandonment suit of 0.75 immersed Clo insulation.

Group II

- Professional crew of maritime shipping companies inshore / offshore
- Crew of offshore oil rigs

The second group comprises all those who work on the water for a profession and face the possibility of having to abandon ship. Their normal working clothes are standard industrial work dress. In the event of the requirement to abandon ship, they don a 0.75 Clo insulated immersion suit, or what is currently called a ship abandonment suit, within one minute. The following examples demonstrate that it works if worn and the penalties for not wearing it.

On 16 January 1998 en route from Rotterdam to Montreal, the Flare broke in two in severe weather conditions and sank 45 miles south west of Saint Pierre et Miquelon. Only four seamen were rescued. Sgt. Isaacs, the SAR technician who conducted the rescue reported that four men were alive and clinging to the top of a lifeboat. Three were severely hypothermic due to inadequate clothing (body core temperature was recorded as 26° to 28°C), but the fourth had donned every item possible before abandonment and was in very good shape. Twenty-one seamen died from a combination of drowning and hypothermia. All bodies that were rescued were lightly clothed, most were not wearing shoes or socks. In this case, if the seamen had worn a good ship abandonment immersion suit, they would have likely survived. A good example of the effectiveness of the ship abandonment suit was in the case of the deckhand from the Patricia MacAlister accident who donned his immersion suit (Reference 161). He was picked up several hours later in the Gulf of St. Lawrence, whereas the five other tug crew did not leave time to do this and likely died from drowning produced by cold shock. There are several other accidents on the Canadian and American coastline where ship abandonment survival suits would have been beneficial. (Marine Electric (1983), Charlie (1990), Protektor 1991, Gold Bond Conveyor (1993)). There is no question that immersion suits protect people from the four stages of immersion in cold water, but they are not an absolute guarantee.

> B.C. fishing boat sinks, killing two (The Sunday Herald, October 28, 2001)
>
> Victoria - Two men died but two others survived after a Comox, B.C., fishing boat sank in heavy seas off the northern tip of Vancouver Island. Crew member Beauchamp Englemark, 27, of Comox resident, was the first of the Kella-Lee's four-member crew to be found. He was clad in a survival suit when rescuers pulled him aboard the coast guard vessel John P. Tully about 7:30 Friday. The body of one crew member, also wearing a survival suit, was found about noon Friday and the body of a third, not wearing a survival suit, was recovered about 3 p.m. The fourth man, in a survival suit and in a lifeboat, was spotted just before 4 p.m. and plucked out of the frigid water in good condition about 5:15 p.m.

Why one of the two men died in the fishing accident off British Columbia while wearing an immersion suit is not known. It could be that the suit was not secured correctly and flooded, it could be the flotation angle in the water was poor and the man drowned from inhaling a wave, or he could have died from cardiac arrest. Until we educate the investigators to ask the correct questions and to teach the pathologists what testing and examination to conduct, it is only possible to second guess the causes of death.

As emphasized in the paragraph above on the Group I occupations, good training is equally essential for the Group II occupations. All personnel who work on or over water should know the dangers of sudden cold water immersion, where to find and how and when to don the immersion suits. In the very recent accident, that occurred in January, 2002, it does not appear that there were enough immersion suits on board, and no one bothered to don them either. The 14 crew had a very lucky escape.

> Sailors tell of harrowing rescue in storm. (The Globe and Mail. January 29, 2002)
>
> Sailors who scrambled off a ship in the middle of a raging North Atlantic snowstorm say a broken pump caused their vessel to fill rapidly with water. The captain of Sjard, a German-owned, dry-bulk carrier, said he and 13 other crewmembers climbed aboard a lifeboat, strapped themselves in and launched it overboard after a bilge pump malfunctioned Sunday. Mr. Scharbatke said none of the men donned the three survival suits that were aboard the vessel. Mr. Scharbatke said that although weather conditions during the rescue operation were awful, with roiling seas, winds of more than 90 kilometres an hour, snow and 5C water temperatures, no one panicked as they abandoned ship and waited in the lifeboat for help to arrive.

If one considers that prior to 1945 there were only rudimentary immersion suits in existence, and prior to 1983, there were basically no immersion suits commercially available for ship abandonment, then the IMO standard has served well to implement their availability. By and large, the suits are very good for protection against hypothermia. All credit should be given to the researchers, industry and financial backers in achieving this. A study by Brooks et al (2001) (Reference 31) on 357 students attending a Basic Survival Training Course at Survival Systems Training in Dartmouth, Nova Scotia showed that there was general satisfaction with the suits and confidence that they could survive. The problem of interface with the lifejacket is still present. Understanding the length of time it takes to revise the standard, it is probably best to leave it alone. The next step for this group is the development of a new integrated suit system standard, an effective, self-righting test using a manikin, and a re-enforcement that a good training program is necessary. The exciting news is that Shell, the Shark Group and the University of Portsmouth, UK have now produced and are using the first generation of such a system.

Group III: Passenger Immersion Suit Systems

Group III

- Passenger of cruise ships operating in water below 15°C
- Passengers of small tourist vessels (whale watching etc.)
- Passengers of year-round ferries (i.e Nova Scotia to Newfoundland and Digby to Saint John, etc.)
- Passengers of ferries in the spring and fall (i.e. Great Lakes and west coast, etc.)

The third group of people who require protection who so far have been totally omitted are tourist passengers of cruise ships, passengers on ferries crossing large expanses of cold water, i.e. Digby, Nova Scotia to Saint John, New Brunswick; Sydney, Nova Scotia to Newfoundland; Yarmouth, Nova Scotia to Bar Harbour or Portland, Maine; passengers on Great Lakes ferries; passengers on ferries off the west coast in spring, fall and winter; and a whole range of smaller vessels that conduct whale watching, fishing trips etc., both inshore and offshore. For them, the primary threat is drowning from cold shock and swimming failure. One has to survive the first two stages of immersion before becoming hypothermic. If rescue is slow, then obviously hypothermia and post rescue collapse become a serious threat. It cannot be emphasized too much that getting out of the water, or even half out of the water is the key to survival. Remaining immersed is very, very dangerous. The objective for the future is to have ships fitted with all dry evacuation systems, so that the survivor either never gets wet, or only wet for a short time. However, technically to achieve this is not easy, particularly under high degrees of list. The Estonia accident is a good example where in spite of the list, a considerable number of people made it to the upper deck. One witness stated that from his part of the ship, at least 100 people made it to the upper deck. They all theoretically should have survived, yet many as we so tragically saw from the statistics of the second World War died in the survival phase. We seem to have forgotten this lesson.

> Around that time some were passing lifejackets from hand to hand and people were trying to put them on as best they could...a man was standing composed and assured trying to calm those who were frightened. He arranged a human chain to distribute lifejackets from an open container. He saw that everyone got a lifejacket and also instructed and helped passengers to put them on.

Many of these were to die in the cold water. If everyone had been given an immersion suit, there would have been an improvement from the 852 casualties (Reference 43).

How should these people be protected? There is a simple solution to this problem. Currently, these passengers are each issued a large bulky SOLAS approved inherently buoyant lifejacket. Anyone making their way from a cabin to the upper deck for abandonment when the ship is listing or flooding has an impossible task to do this when wearing one of these or trying to drag it behind them along the companion ways, stairwells and stairs. The idea now being introduced in Europe comes from the method used to protect naval personnel in a ship abandonment. In the Navies, each sailor is provided with a belt on which is hung two small pouches. One contains a lifejacket and the other contains a once-only quick-don immersion suit. On the upper deck, just prior to abandonment, the lifejacket is unbuttoned from the pouch, unrolled, placed over the head and orally inflated, nothing could be so simple. Then the second pouch is unbuttoned, the suit unrolled and donned over the lifejacket and sealed at the neck by the drawstring. The person is then physically prepared against drowning from cold shock and swimming failure. In the short term, the suit provides protection for approximately one hour from hypothermia in the water and once in the liferaft virtually indefinitely.

The concept for passengers on ferries or cruise ships etc. can be very similar. It is very important to refer to the lifejacket and immersion suit as an integrated immersion suit system, and it should be certified as such against a performance standard. The reason for this is that if this does not occur, a standard will be written around a certain system and leaves little flexibility for improvement and innovation. An immersion suit and lifejacket developed as one system, tightly packed on a belt or jacket (allow the manufacturer to come up with the design), should be provided in each cabin for each occupant. In addition, there should be 100% additional systems located on the upper deck, instead of the conventional lifejackets. The system should not be tested against a lifejacket or an immersion suit standard, but against its own performance standard. This should also be simple. It should:

- Protect from cold shock and swimming failure
- Protect from hypothermia in 5°C water for 2 hours (basically the ISO Class C standard)
- Protect from hypothermia in a liferaft for 24 hours
- Protect the oronasal cavity and prevent drowning
- Be self-righting in 5 seconds from a face down position in turbulent conditions
- Be easy to don
- Be easy to use to climb into a liferaft form the ocean
- Should fit all sizes of male and females

The reason why it should be tested against a new performance standard is to get away from such concrete ideas that an inflatable lifejacket must be dual chambered. In fact, if a manufacturer can design a puncture proof single chambered inflatable element within the immersion suit system that incorporated one or two layers of the suit itself, then this is a positive step forward in design. Canada has the opportunity to lead the world in developing and implementing such a performance standard and Canadian industry could develop the new system.

Quick-don immersion suits and simple inflatable lifejackets as described above are now commercially available. Therefore, in the short term (2–3 years), simple quick don immersion suits should be required on all vessels carrying Group III personnel. In the event of very small vessels and lack of stowage, then all passengers must wear an inflatable lifejacket particularly if the water temperature is below 15°C. Once the integrated suit system standard is developed and equipment commercially available (3-5 years), then this system should be required on all vessels carrying Group II personnel. The issue of how much insulation is required in the system is difficult to answer because it depends on so many factors. The author would like to see 0.75 immersed Clo value suits on every vessel, but practically and economically this probably is not feasible. The majority of people die in the first four minutes of immersion and therefore to get the best value for money, save the most lives and help operators to comply, a simple 0.25 immersed Clo dry suit which can be packed tightly and needs minimum maintenance is the way ahead.

Current Regulations

Currently, written in English, there appear at least 11 sets of regulations ratified or in draft pertaining to immersion and related suits. There must be others that remain in confidential files of different maritime and offshore oil industry health and safety committees. These are:

- Canadian General Standards Board. Marine Abandonment Immersion Suit Systems. CAN / CGSB-65.16-99. (Reference 34)
- Canadian General Standards Board. Helicopter Passenger Transportation Suits. CAN / CGSB-65.17-99. (Reference 33)
- Canadian General Standards Board. Marine Anti-Exposure Work Suit. CAN / CGSB-65.21-95.
- US Coast Guard Department of Transportation. Life Saving Equipment. Part 160 Chapter 1 of 46 CFR. (Sub-part 171 – Immersion Suits, Sub-part

174.-Thermal Protection Aids.) Consolidated Edition 2001.

- IMO SOLAS. Chapter III. Lifesaving Appliances and Arrangements.
- IMO International Life-Saving Appliance Code 1997.
- Civil Aviation Authority. Helicopter Crew Members Immersion Suits. Specification No. 19, Issue 1. 15 April 1991.
- Air Standardization Coordination Committee. ASCC Standard 61/12 (Methodology for Evaluation of Anti-Exposure Clothing in Cold Water Immersion Using Human Subjects)
- Final draft pr EN ISO FDIS 15027-1-3 Immersion Suits: Part 3: Test Methods. 26/08/1999.
- Draft Issue 2 JTSO-XXX Helicopter Crew and Passenger Integrated Immersion Suits for Operations to or from Helidecks in a Hostile Sea Area.
- Personal Protection of Helicopter Passengers in the Event of Ditching. Shell Health, Safety and Environment Committee. February 1996.

Highly commendable is the fact that the only industrial standards that appear to be publicly available have been produced by the Shell group of oil companies.

Generally speaking, there is very little difference in each of the regulations. The next step is for us to apply what we have learned from these standards and introduce a new standard for an integrated immersion suit system. However, not as in the case of the draft JTSO integrated immersion suit, to write the standard around a system that has already been developed.

The personnel in Group I who require a constant wear suit should be offered a standard which gives them a choice depending on their environmental conditions. The draft ISO standard is a good basis for a start because it offers four levels of protection. However, it should be used as a guideline for the integrated suit system standard.

The personnel in Group II with their 0.75 immersed Clo suit are well protected from all four stages of the immersion incident with the current standards. With hindsight, it is now realized that there is a problem with the lifejacket self-righting these suits. However, taking the overall situation into consideration, the suits are good and to date no one has demonstrated to the author that anyone has perished as a result of the incompatibility between immersion suit and lifejacket. More likely, they have perished because ship abandonment type immersion suits were not carried or not donned. The standard should be retained until a new integrated standard is developed.

The personnel in Group III are currently unprotected. As a matter of urgency, in the short term (2 years), operators should provide passengers in vessels operating in water below 15°C with the quick-don Navy style immersion suit. This is commercially available in Canada. In the long term (5 years), a new integrated immersion suit standard should be developed for them. For operators who read this report and think that the introduction of a quick don suit will be a waste of time and money for them, this is not the case. This will be a huge step forwards in the protection of their passengers and it should not be difficult to modify their in service suits to the new specifications, or grandfather them for say another five years.

Future research should involve the development of simple, cheap validated flotation and thermal manikins to do this. Confidential work which is currently underway makes the author believe that in less than two years this will be achievable. Then it will only be required to represent the thinnest and tallest subjects for the thermal test. This will mean human testing will only have to be done in cold water for radical improvements in current systems or entirely new concepts. All the remainder of suit testing can be done using a manikin. For the flotation manikin, again depending on funds, and the will to get on with the job, this could be achieved in five years.

Summary of Chapter 6

This chapter discusses who needs protection, what regulations are in place and what regulations are missing.

- The first consideration must be a careful assessment of the overall nature of the threat before deciding on a solution. Providing a solution to one facet alone is unlikely to solve the problem.

- In the attempt to delay hypothermia, one is frequently embarking on a pathway, which is not only economically expensive, but involves such a degree of sophistication in suit design that it may fail when donned quickly in an emergency.
- As the majority of deaths following immersion occur in the early stages 1 and 2 before hypothermia develops, preventative measures should be directed toward providing against the short term incapacitating effects of cold and protection from drowning.
- There are thirteen professional categories who require either a constant wear suit (Group I), a ship abandonment suit (Group II) or a passenger immersion suit (Group III)
- Some of the professions in Group I have been overprotected with 0.75 immersed Clo. They should be offered alternative suits with insulation ranging from 0.25-0.5 Clo based on the draft ISO standard where four levels of insulation are prescribed.
- Group II professionals are well protected with their 0.75 immersed Clo suit, but a new integrated suit standard should be developed to include the lifejacket. This will solve the problem of inability of current lifejackets to self right humans wearing high buoyancy suits.
- Group III passengers sailing in water below 15°C are unprotected. In the short term, operators should provide them with the Navy style of inflatable lifejacket and quick don immersion suit. In the long term, a new integrated passenger immersion suit standard should be written.
- The key factors involved in the development of an integrated immersion suit system are listed.
- A list of the current immersion suit standards is included.

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